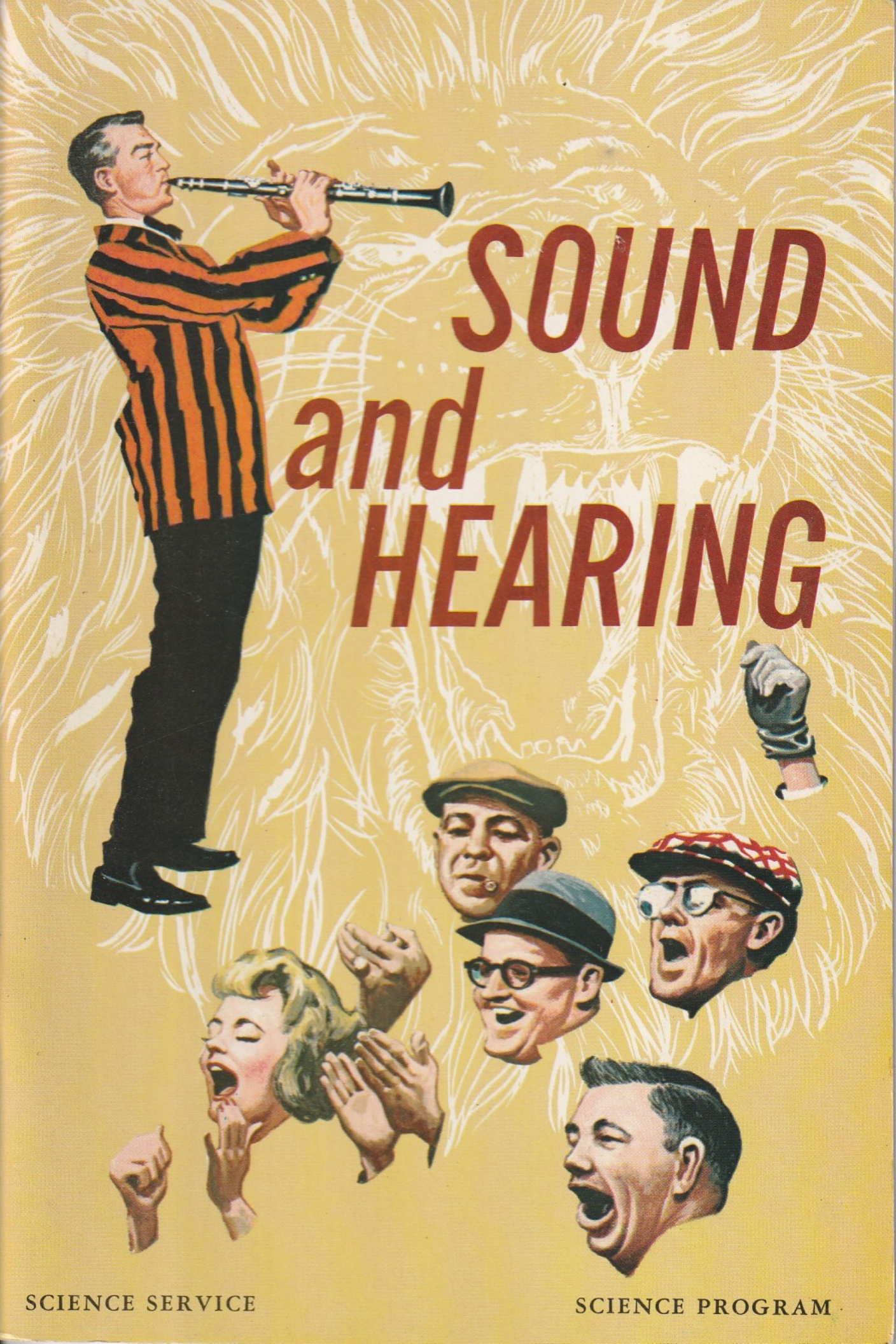

SCIENCE SERVICE

SCIENCE PROGRAM

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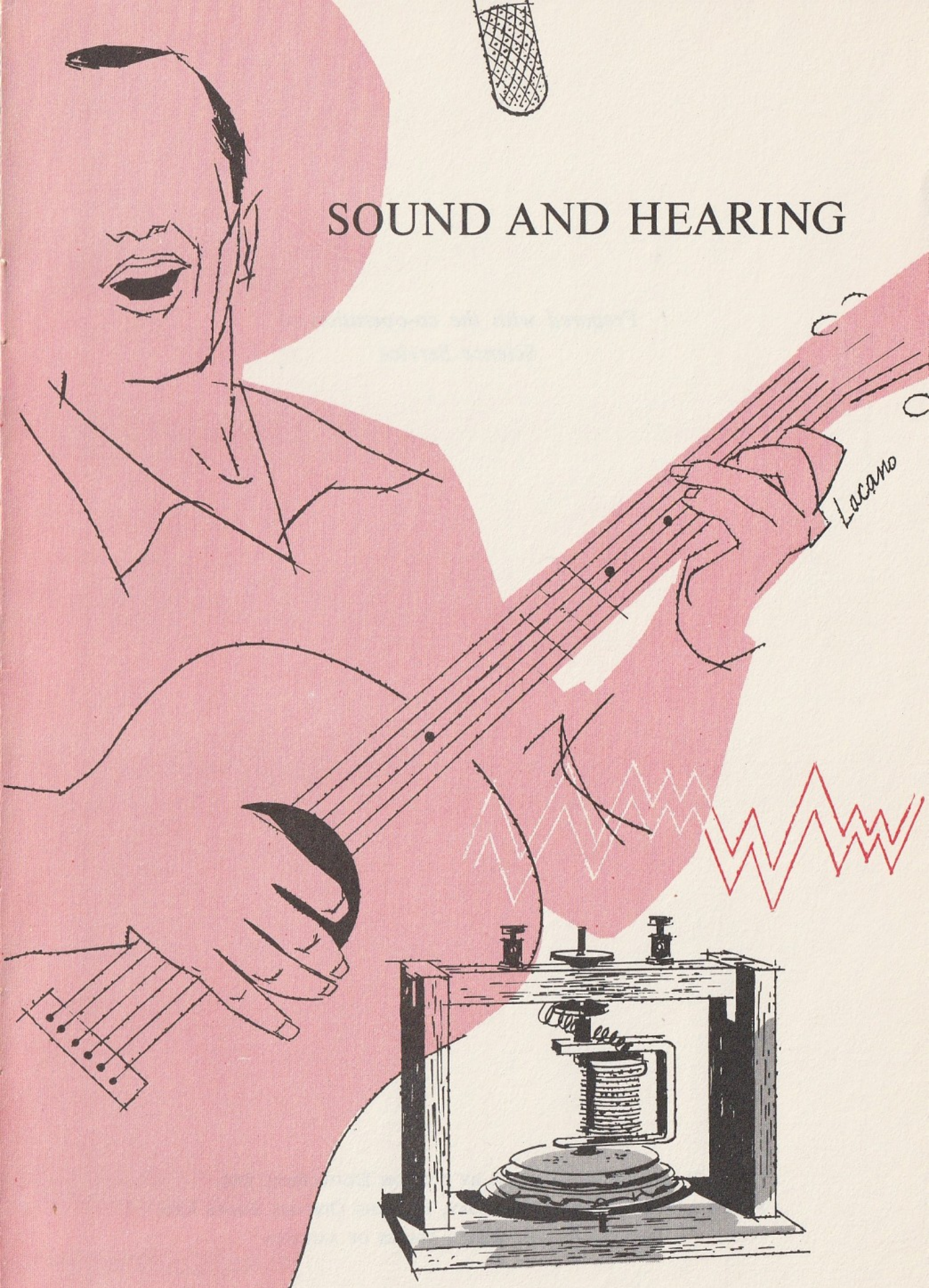
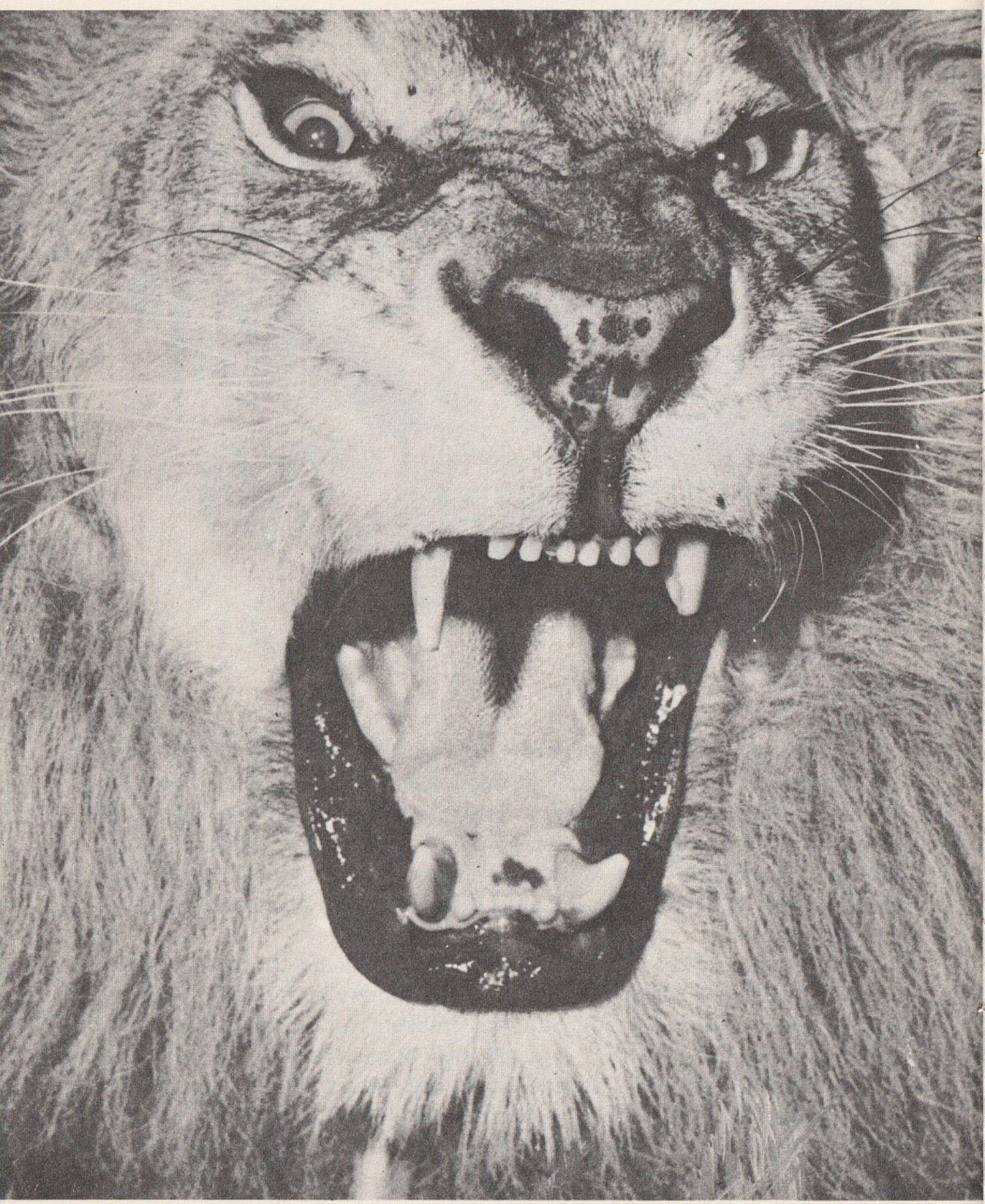
SOUND AND HEARING



SCIENCE PROGRAM

PREHISTORIC MAN MAY HAVE HAD a very practical way of evaluating other animals. He probably divided them, mentally, into two categories: those that were for eating, and those that would eat him if he didn't keep his wits about him. This would have been a sensible approach, because his survival in a world teeming with other animals depended on his ability to detect them, identify them correctly, and react appropriately to them.

The caveman who couldn't locate edible animals, or who plunged unwarily through a thicket into the jaws of a hungry lion, had a very short life expectancy, and consequently was unlikely to father children. The caveman who had superior eyesight and hearing and sense of smell, and learned to use each sense to help the others along, was able to track down food and avoid the animals that considered him to be fair game. The individual with acute senses lived to grow up and have children.



1. A TIGER SNARLS

Oddly enough, the danger of being attacked by a tiger, or any of the big cats, may be less when they are snarling. They may swipe with a paw but the lethal charge is normally made in virtual silence, taking the victim by complete surprise.

His children went through the same weeding-out process. Those with dull sensibilities died young. Those with the most acute senses passed these faculties on to *their* children, and after this process was repeated through succeeding generations for a few hundred thousand years, human ears became refined to the point where they became highly efficient "second eyes", which could tell by sound alone the distance, direction, size and texture of the object making the sound, and could often correctly identify it simply from the sound it made.

Hearing, combined with man-made sounds, provided the means through which man could communicate facts and ideas. The growing need to record speech in a permanent form made him evolve an alphabet whose symbols represented the sounds of speech, so that future generations could build upon the knowledge of their ancestors, without having to discover everything for themselves.

What is sound? It is often defined as "something we can hear". Let's back off a bit and ask, instead, what is hearing? Hearing is a sensation, like touch and taste and smell. It is not a physical thing that can be

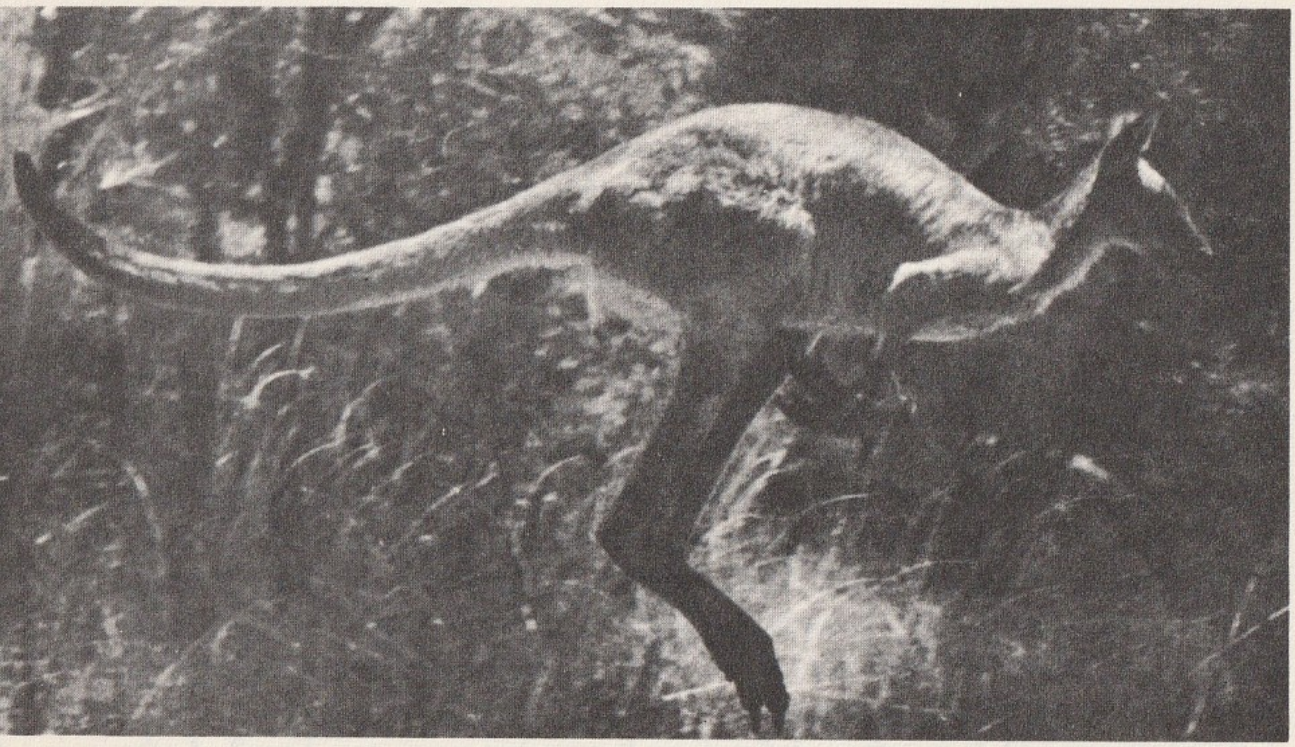
seen, weighed or touched, but is, rather, a "state of mind". It is a mental *impression* that occurs in response to something that is taking place outside our bodies. We have chosen to call that something a "sound". So, a sound is what our hearing mechanism is designed to perceive.

Note that this definition does not require a hearer-on-the-spot. All it requires is that the something—the sound—be something our ears are *intended* to respond to, with the understanding that it *could* be heard if there were ears to hear it.

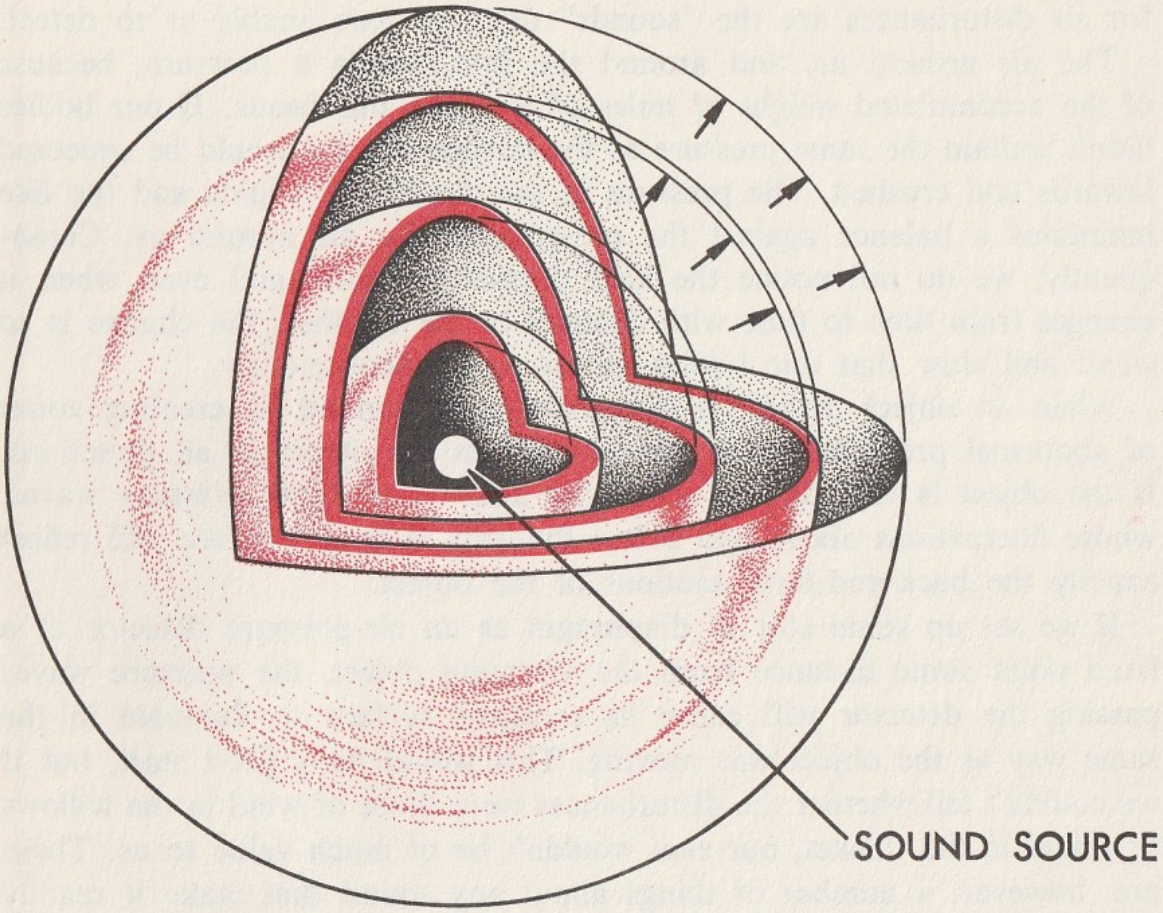
Sound Waves in Motion

WHAT DO OUR EARS respond to? Well, what would best serve to tell us a lion is stalking us?

As long as there still is time to avoid the lion, he is separated from us by a space filled with air. If we are to learn of his presence before his teeth contact us, something must travel from him across the intervening space to us. If we were looking at him, light rays reflecting from him



When excited, an Australian kangaroo bounds along on his immensely strong hind legs, creating an almost unique sound—a combination of thumps and twig-snapping.



Sound waves are radiated as concentric shells of pressure, like balloons expanding one inside the other. The more they expand, the more their total energy is spread out, so the sound pressure gets progressively weaker.

would register on our eyes as a lion-looking image. But if we were facing the other way, the rays would not reach our eyes. If the wind were blowing our way, tiny and unseen particles of his unwashed hide would be carried to our nose, and we would smell him. But if there were no wind, the sense of smell would be of no help either.

There is one thing left. Even the most prudent lion will step on an occasional twig, and when this breaks, its sudden movement will stir up the air around it, sending tiny disturbances off through the air in all directions. If we could detect these in some way, and could interpret them as breaking-twig disturbances, we would know that *something* was snapping twigs nearby, and we could turn our eyes toward it to identify it. This is how keen ears saved many a caveman from an early end;

for air disturbances are the "sounds" that our ears enable us to detect.

The air around us, and around the lion, exerts a pressure, because of the accumulated weight of miles of it above our heads. If our bodies didn't contain the same pressure as the outside air, we would be squeezed inwards and crushed. The pressure of our flesh, body fluids and the like maintains a balance against the pressure of the air around us. Consequently, we do not notice the air's normal pressure, and even when it changes from time to time with changes in the weather, the change is so small and slow that our bodies adjust to it unconsciously.

When an object moves, it disturbs the air around it, creating zones of abnormal pressure that travel away from the object in all directions. If the object is vibrating, it sends out a *series* of these pressure waves, whose fluctuations above and below the air's normal pressure will reflect exactly the back-and-forth motions of the object.

If we set up some sort of diaphragm as an air-pressure detector at a fixed point some distance from the vibrating object, the pressure waves passing the detector will cause its sensitive surface to fluctuate in the same way as the object was moving. This would be a good start, but if we couldn't tell whether the disturbances were those of wind in the willows or a lion in the thicket, our ears wouldn't be of much value to us. There are, however, a number of things about any sound that make it readily distinguishable from other sounds, and one of these is its *strength.*

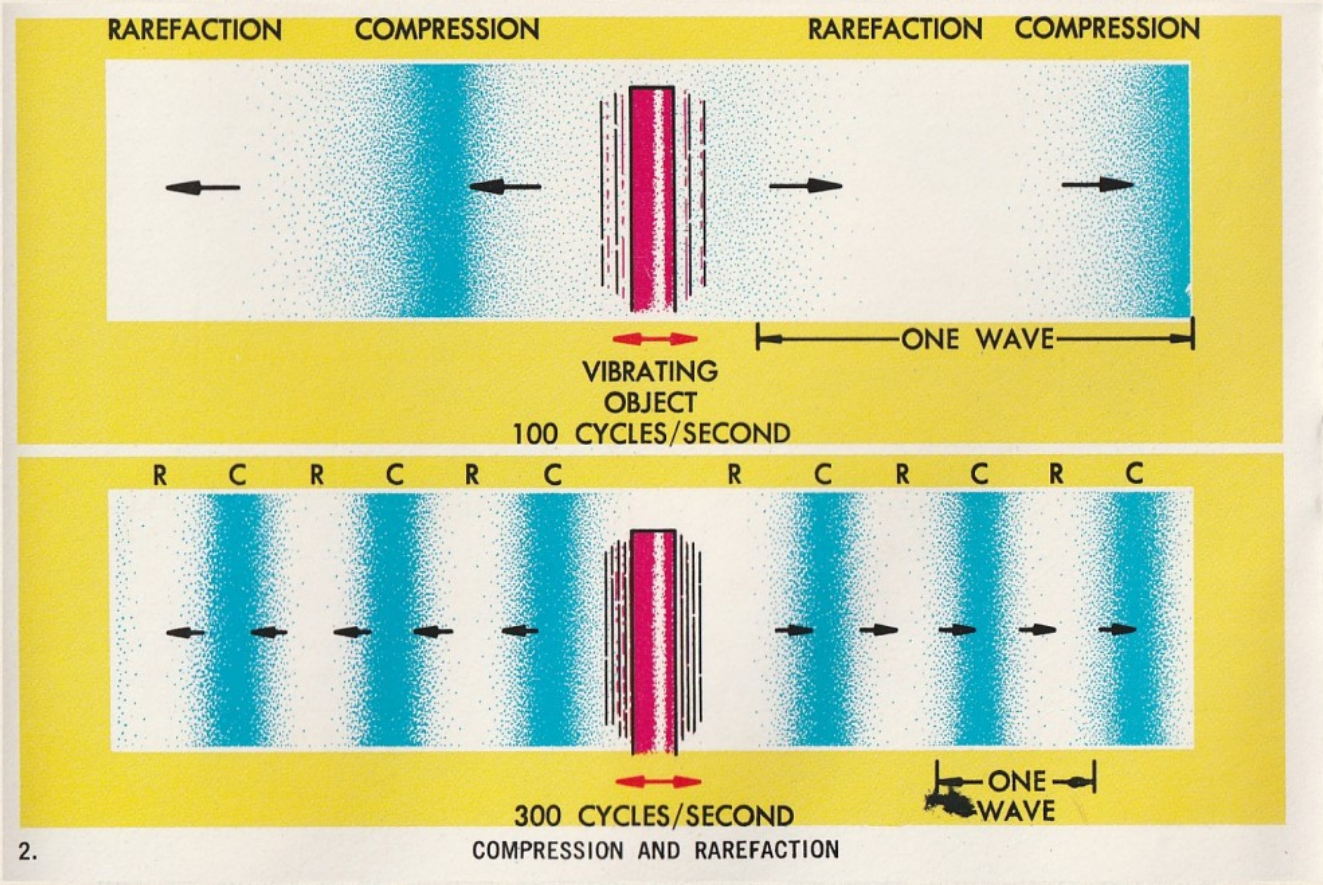
Some power must be expended to impart sound waves to the air, and the more power that is represented by each wave, the stronger will be each variation in pressure. Sound waves spread out as they travel from their source, and the more they spread themselves, the weaker they get. So while we may conveniently measure *total* sound power in terms of watts, it makes more sense to measure the strength of a sound in terms of how much its pressure varies above and below normal atmospheric pressure.

The basic unit of air pressure is the *bar* (from the Greek word *baros,* meaning weight—of air, in this case), which is why a device that measures atmospheric pressure is called a *barometer.* The bar is about fifteen pounds per square inch. But since sound waves are very small pressure changes when compared with the pressure of the atmosphere, we conveniently measure sound pressures in millionths of a bar, or *microbars.* Our ears don't "measure" these changes in pressure, but they do respond differently to different amounts of sound pressure, giving us some idea of the extent of the motions that caused the sound.

Another difference between different sounds arises as a result of the *rate* at which the object is vibrating. All sound waves travel through the air at a speed of 1,100 feet per second. Since the speed of each wave is always the same, the distance between successive waves will depend on how soon one follows on the heels of the preceding wave.

If the object completes, say, twenty-two cycles of vibration every second (about as fast as the very deepest bass strings of a piano), the waves will be spaced a long distance apart—fifty feet, in this case. If the cycles occur more frequently, at a rate or *frequency* of, say, 2,200 cycles per second, the waves will be shorter. At 2,200 cycles per second, the wavelength will be one foot, because if the waves travel 1,100 feet every second, they will travel one foot in 1/1,100 of a second.

A sound's wavelength always increases as its frequency decreases, but the frequency of the air pressure variations at our ears will be changed appreciably if we are in rapid motion relative to the sound source. The motion of either one, sometimes both, takes place relative to the air, which is standing still, and thus its own speed is to be added to or subtracted from the speed of the sounds travelling through the air. This change in frequency is the so-called Doppler effect, which makes the sound of a



2. COMPRESSION AND RAREFACTION

A vibrating object sends out a series of alternate compression and rarefaction waves. The speed of each wave is always the same, so the length of each wave depends on how rapidly the object vibrates. The air's normal atmospheric pressure is represented by medium blue shading *above*.

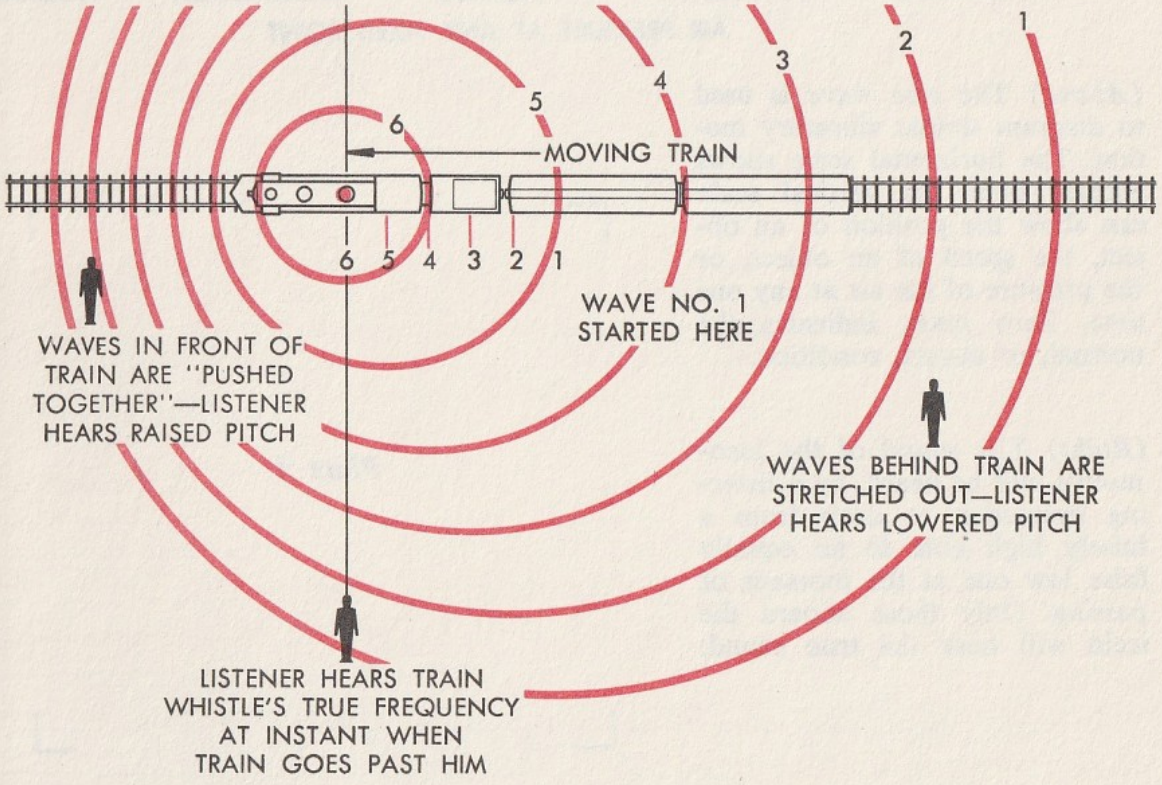
train whistle or a car horn change its pitch from high to low at the moment it passes us. The greater the speed, the greater will be the change of pitch.

In order to vibrate, an object (one part of which is restrained) must have enough stiffness to return to its normal position if deflected. It must also have enough mass to keep it moving once it is set in motion (inertia). If these requirements are met, here's what happens: something pushes the object to one side and then lets it go. Once in motion, its inertia tends to keep it moving, but its stiffness tries to restore it to its normal at-rest position. The stiffer the object, the sooner its inertia will

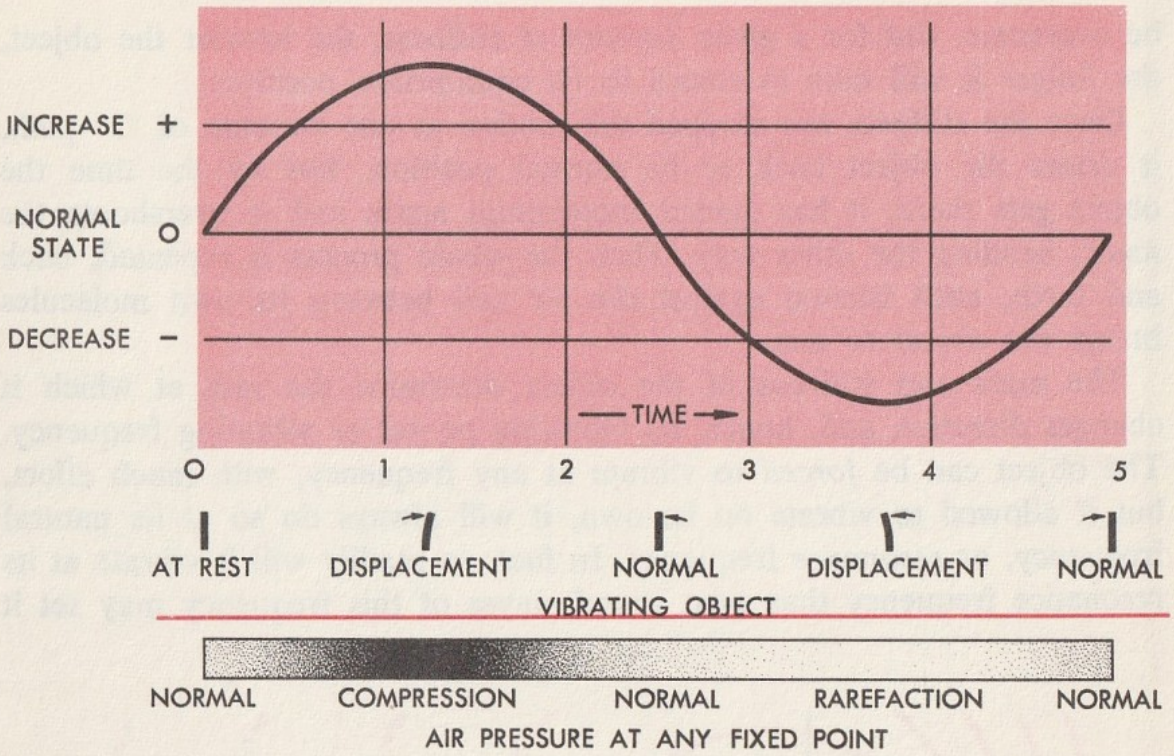
be overcome. But for a given amount of stiffness, the heavier the object, the *longer* it will take to return to its equilibrium position.

Once the stiffness has stopped the motion at one extreme of the path, it draws the object back to its normal position. But by the time the object gets there, it has gained momentum again and it overshoots the mark, bending the other way. Then the whole process is repeated, back and forth, until friction against the air and between its own molecules brings the object to rest.

The mass and stiffness of the object determine the rate at which it changes direction and, hence, its vibrating period or vibrating frequency. The object can be *forced* to vibrate at any frequency, with much effort, but if allowed to vibrate on its own, it will always do so at its natural frequency, or *resonance* frequency. In fact, so readily will it vibrate at its resonance frequency that even sound waves of this frequency may set it

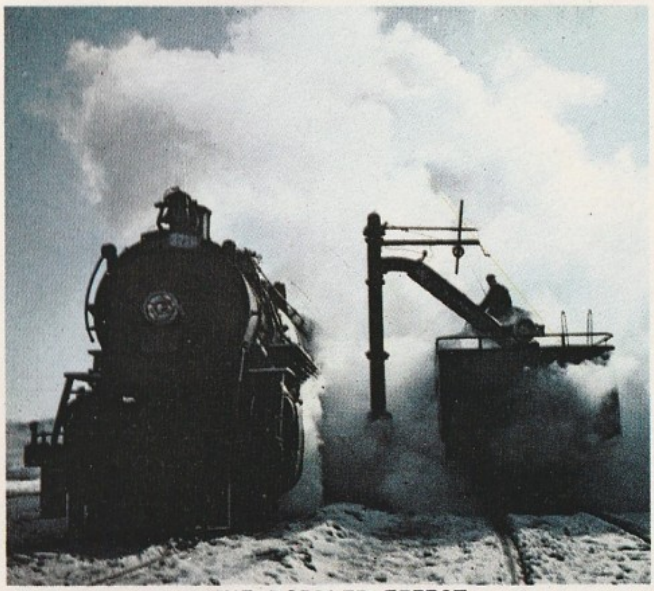

1
2
3
4
5
6
MOVING TRAIN
6 5 4 3 2 1
WAVE NO. 1
STARTED HERE
WAVES IN FRONT OF TRAIN ARE "PUSHED TOGETHER"—LISTENER HEARS RAISED PITCH
WAVES BEHIND TRAIN ARE STRETCHED OUT—LISTENER HEARS LOWERED PITCH
LISTENER HEARS TRAIN WHISTLE'S TRUE FREQUENCY AT INSTANT WHEN TRAIN GOES PAST HIM

The Doppler effect changes the perceived frequency of a sound when its source, or the listener, is in continuous motion. This shows how motion changes the length of the sound waves from a train whistle. If a listener speeds toward or away from a stationary whistle, his speed would be added to or subtracted from the waves in the air, so changing their frequency.



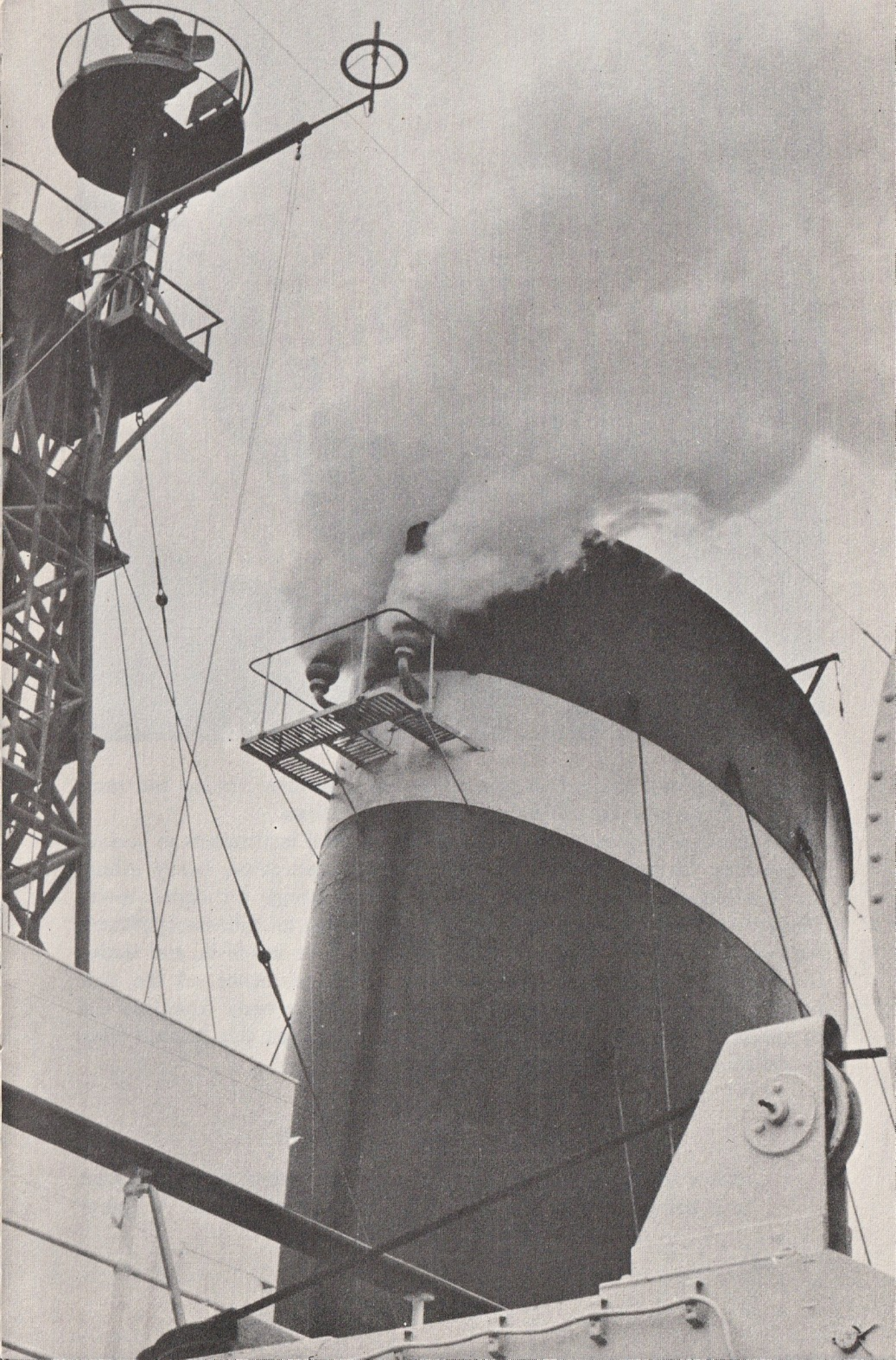
(*Above*) The *sine wave* is used to diagram simple vibratory motion. The horizontal scale shows elapsed time; the vertical scale can show the position of an object, the speed of an object, or the pressure of the air at any one time. Zero mark indicates the normal, or at-rest, condition.

(*Right*) The sound of the locomotive will be heard, by a listening bystander, to drop from a falsely high note to an equally false low one at the moment of passing. Only those aboard the train will hear the true sound.



3. THE DOPPLER EFFECT

(*Opposite page*) Designed to carry over long distances, especially in foggy weather, a ship's whistle is normally two bass notes. This is the S.S. *Washington*.



going. Vibrations induced in one object from another having the same resonant frequency are called *sympathetic vibrations.*

The principle of resonance is used to tune musical instruments to various frequencies. Stringed instruments, for instance, use thick, heavy strings for low-frequency (bass) tones, and thin, light strings for higher tones. The precise tuning of each string is set by adjusting its stiffness (tension). An organ pipe uses vibrations of the column of air inside it, and tuning is obtained by varying the length of the pipe and, hence, of the time required for a wave to rebound (at 1,100 feet per second) from one end of the pipe to the other. The longer the pipe, the longer this journey takes —and the lower its sounding frequency.

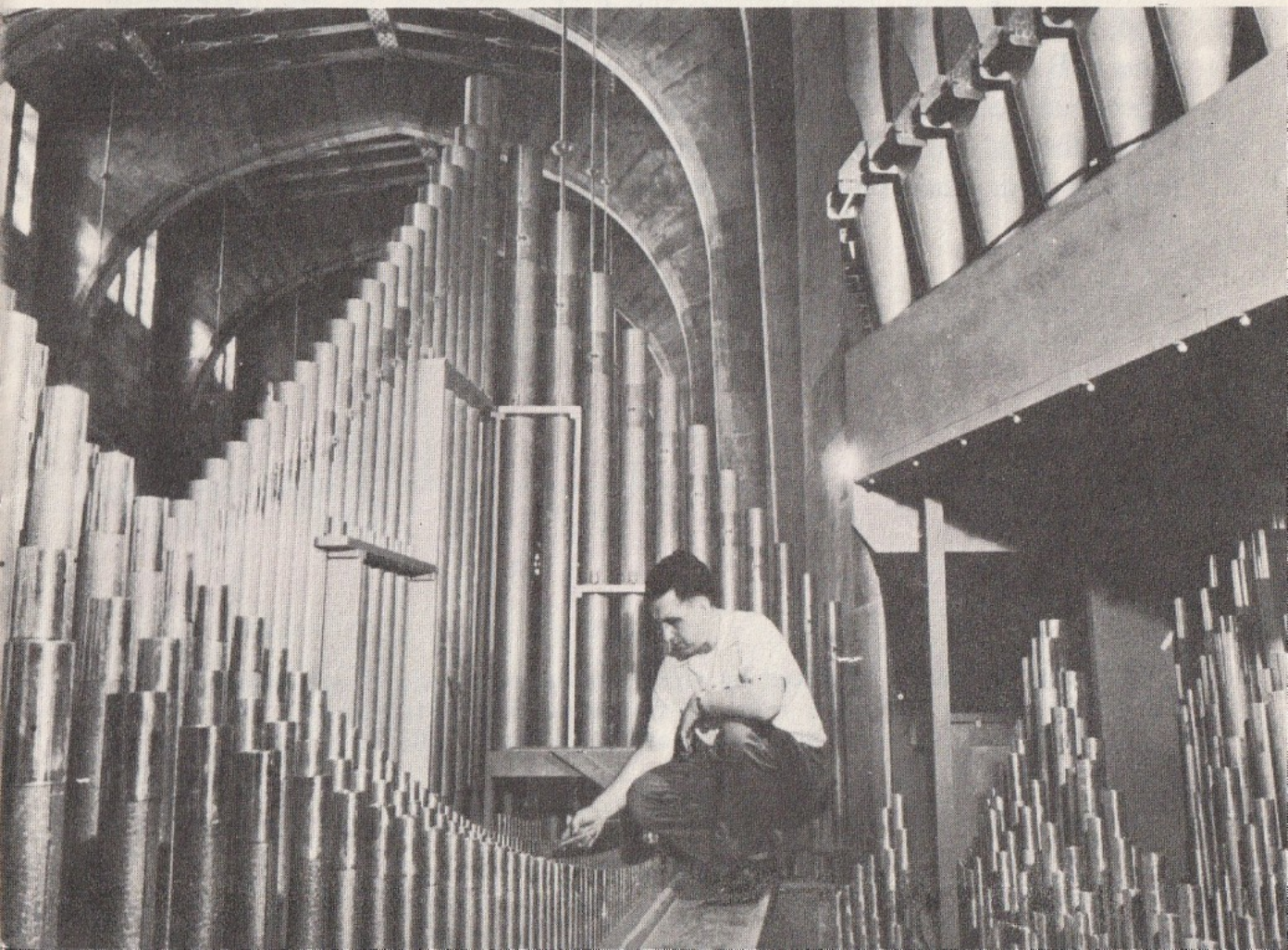
Harmonics and Overtones

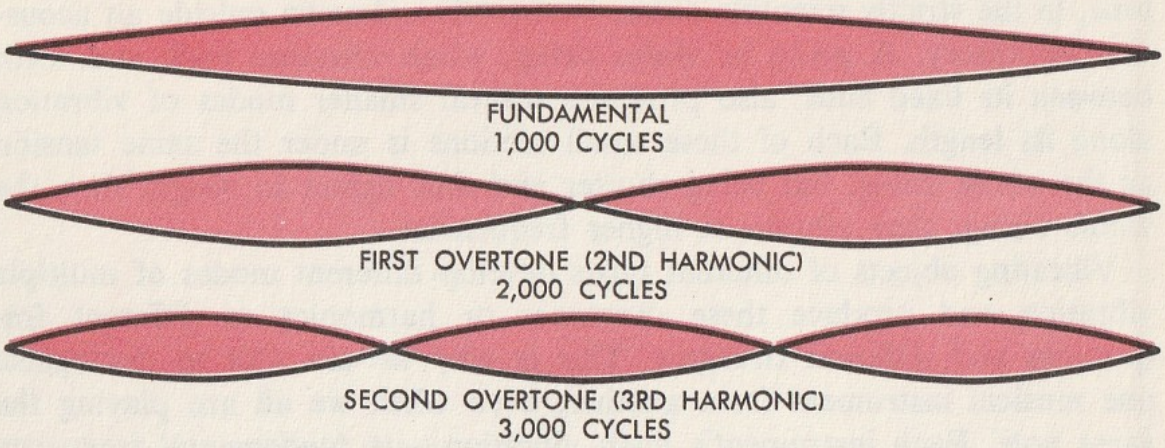
WHEN A MUSICIAN SPEAKS of the purity of another musician's tone, he is being complimentary, but he is not being accurate. A "pure"

tone, in the strictly scientific sense, is virtually unknown outside an acoustics laboratory. A piano or violin string, while vibrating back and forth between its fixed ends, also produces several smaller modes of vibration along its length. Each of these small sections is under the same tension as the whole string, but being shorter and thus lighter in weight than the whole string, they vibrate at higher frequencies.

Vibrating objects of different types develop different modes of multiple vibration and produce these overtones or harmonics at different frequencies and different strengths. This is why we are able to distinguish one musical instrument from another, even when we all are playing the same note. Each instrument's main vibration—its *fundamental* frequency —determines this note; the harmonics determine its quality or "timbre". The harmonic content of a sound can also tell us much about the *location* of the thing that is making the sound.

Tuning a large pipe organ is no small task. There are over 7,000 pipes ranging from ¼ inch to thirty-two feet in the organ of Baltimore's Cathedral of Mary Our Queen.

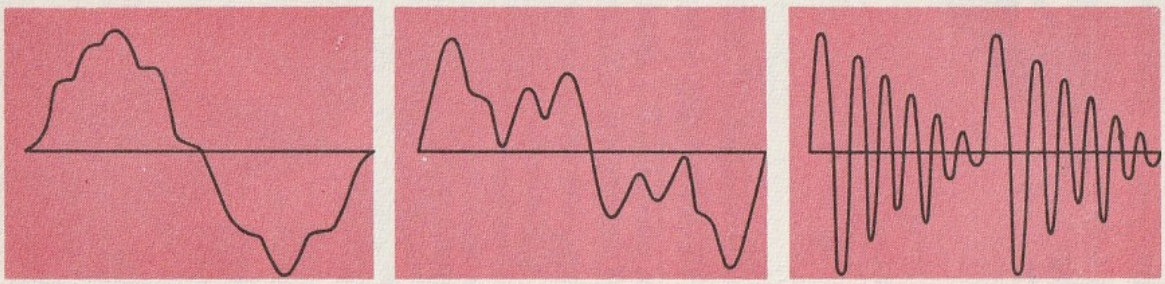




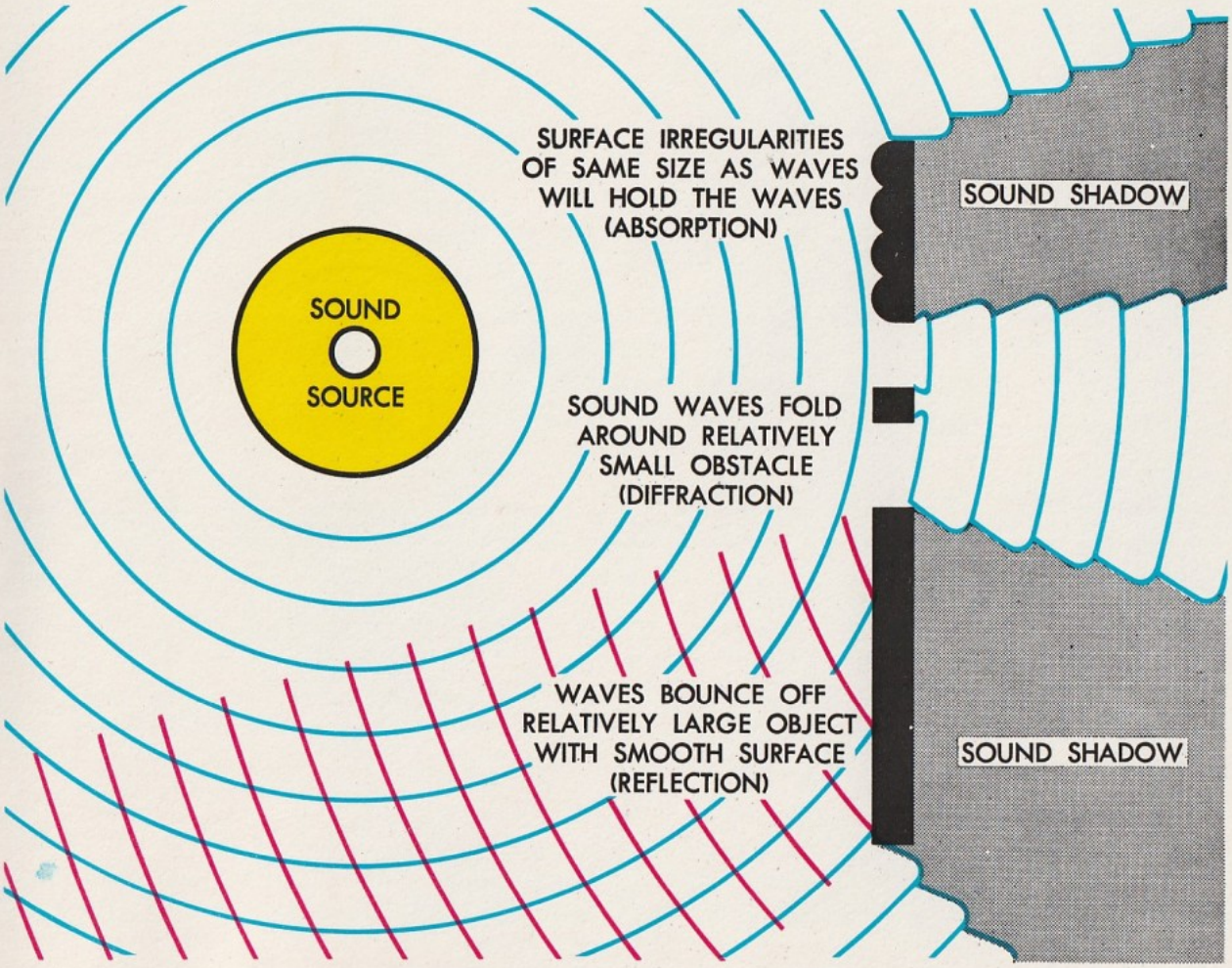
A vibrating object will usually vibrate in sections just as it will as a whole. A string is shown in three different modes of vibration. All three, plus others that yield still higher harmonics, normally occur at once. The result is the complex wave we recognize as "stringed-instrument tone".

In some respects, sound waves behave like light beams. Even though each wavefront is a "wall" of pressure, the waves travel in straight lines directly away from their source, and perpendicularly to the wavefronts. And, like light, they will reflect from some things and be absorbed by others. But, *unlike* light, some sound waves will flow around intervening objects and continue beyond as if nothing were in the way at all.

Whether a sound is reflected, absorbed, or unaffected by an obstacle in its path depends on the size of the obstacle relative to the wavelength



The waveforms produced by vibrations of three musical instruments all playing the same note, or frequency. The differences in their harmonic structures are what make them sound different to us.

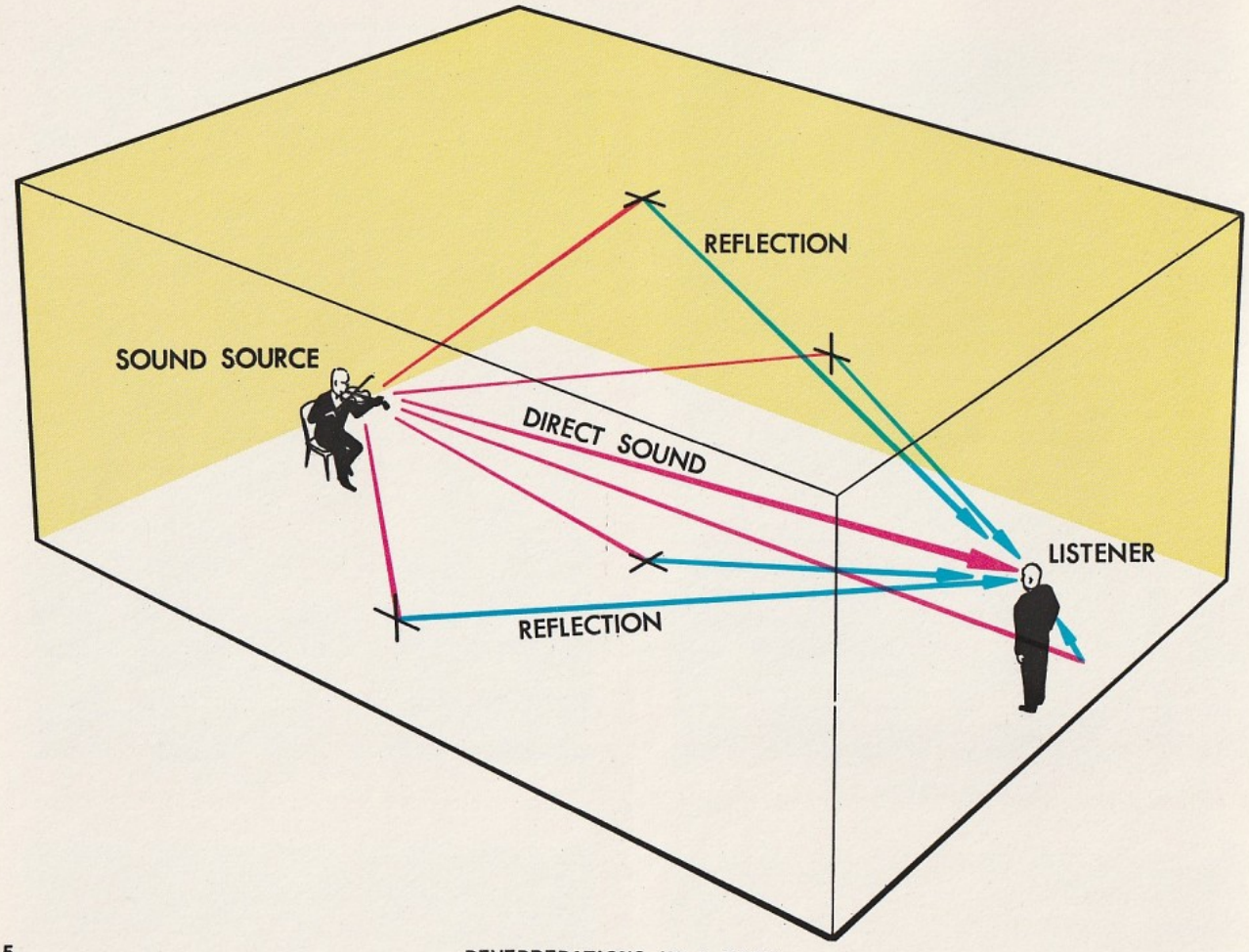


4. ABSORPTION, DIFFRACTION AND REFLECTION

Very rarely can sound just dissipate into "thin air". Normally it is absorbed by large, rough-surfaced objects or echoed back from large smooth objects. It can also be diffracted around objects that are smaller than the wavelength of the sound.

of the sound. Objects that are smaller than the sound's wavelength will not affect the sound waves appreciably. The waves will be refracted around it and will continue unabated. Objects that are considerably larger than the waves will reflect them.

High frequencies are usually the first to be absorbed. Middle frequencies are the next to go, while low-frequency sounds are by far the most durable. This is why the sharp bang of a backfiring automobile, heard from the far side of a large building, sounds like a dull boom. Only the lowest frequencies get around the intervening building.



5. REVERBERATIONS IN A ROOM

The sounds we hear in a room are a mixture of direct sounds and reflections from walls, floor and ceiling. These reflections are called reverberations.

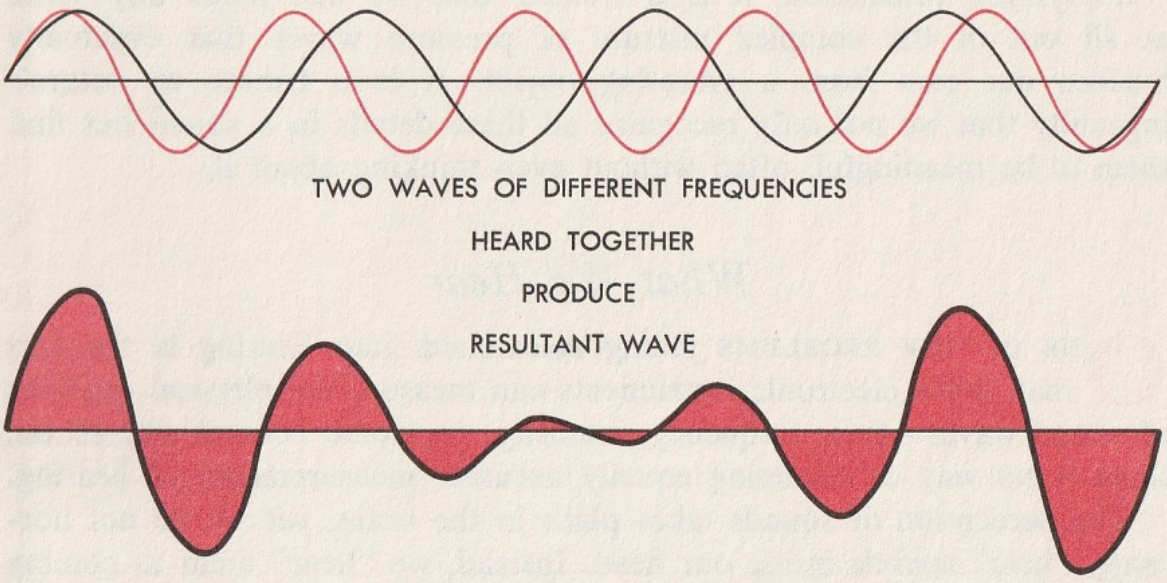
The high-frequency content of a sound can give us some clues to the location of its source; so can the reflected sounds that accompany the "direct" sound. When a sound reaches us from a distance, the direct, unreflected waves reach us first. The reflections, having had farther to travel, arrive later, and give rise to what we call *reverberations*. Usually, the reflections start arriving almost immediately after the direct sound, so they blend with the direct sounds and give them a certain quality of *liveness*. But if the reflections have had to travel very much farther than the direct sounds, they arrive late enough to become audible as separate sounds; we then call them *echoes*.

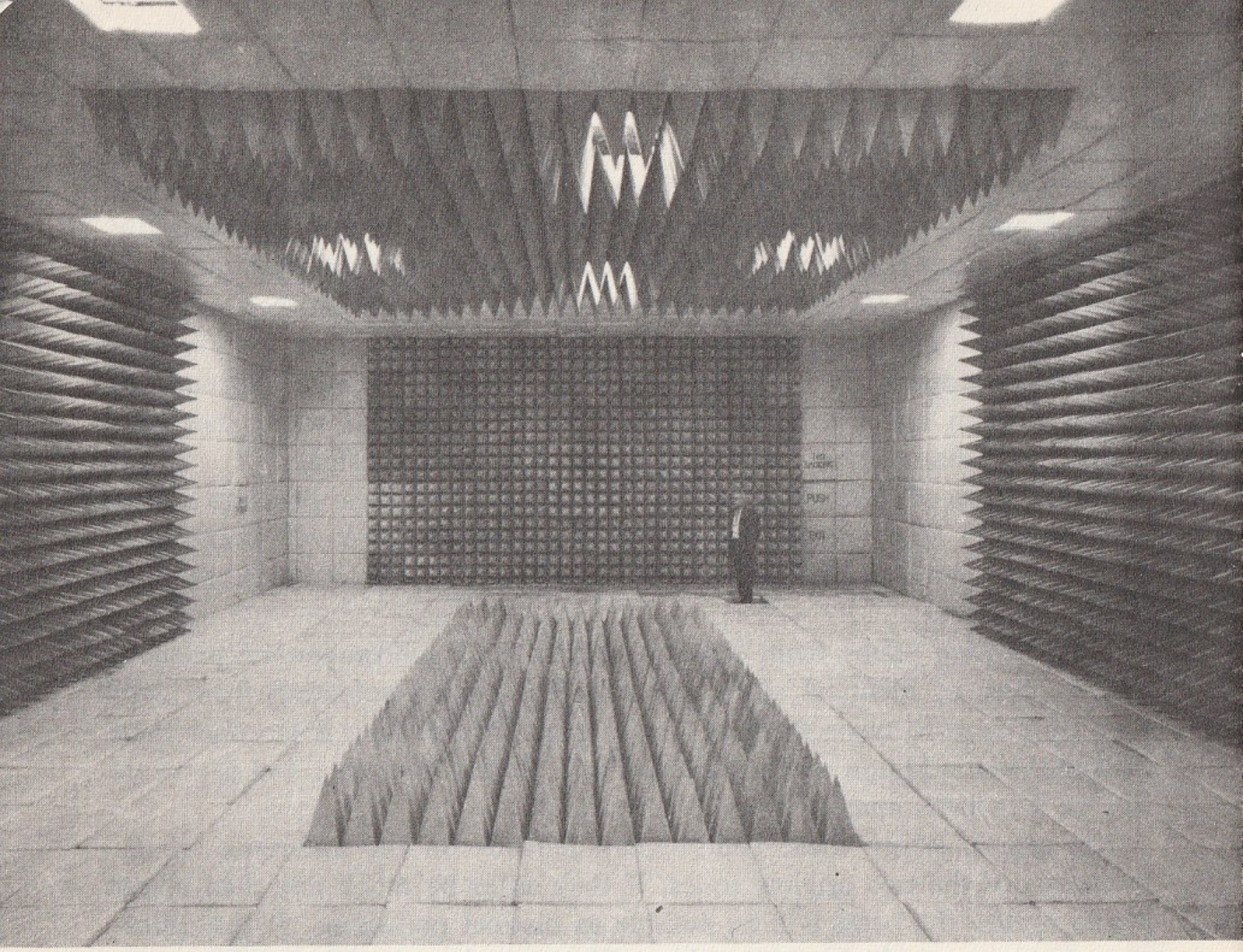
When sound waves are coming from a single source, high-pressure and low-pressure variations follow one another in an orderly succession. But when the sounds come from different directions, as they do after reflection from objects, the pressure waves get out of step with one another and start adding to and subtracting from one another. This is called *interference,* whether it happens to augment a pressure wave or whether it tends to cancel one. In either case the original pattern of sound waves becomes appreciably changed by the time it reaches a distant listener.

If two tones of *different* frequency occur together, their pressure waves will be out of step, too, but in this case the interference will occur at a regular rate, causing periodic pulsations (beats) in the strength of their combined sound.

Since beating stems from simple addition and subtraction of pressure waves, tones of identical strengths will yield beats fluctuating from zero sound pressure to twice the pressure of each. If one tone is stronger than the other, the addition and subtraction will be less complete and the beats will be less pronounced.

The rate at which these beats occur depends on the difference in the frequency of the two original tones. If they differ by much less than about fifteen cycles, the beats will be audible as distinct pulsations. If the difference frequency is higher than about fifteen cycles, the beats will merge together and become audible as a definite third tone accompanying the other two.





This is an anechoic chamber—a room without echoes. Does your singing voice sound better in the bathroom? Not in here! This chamber was built at the University of Michigan to simulate conditions in outer space.

Everything considered, it is a wonder that we can make any sense at all out of the complex mixture of pressure waves that eventually reaches our ears from a vibrating object. It is a tribute to nature's ingenuity that we not only recognize all these details in a sound but find them to be meaningful, often without even thinking about it.

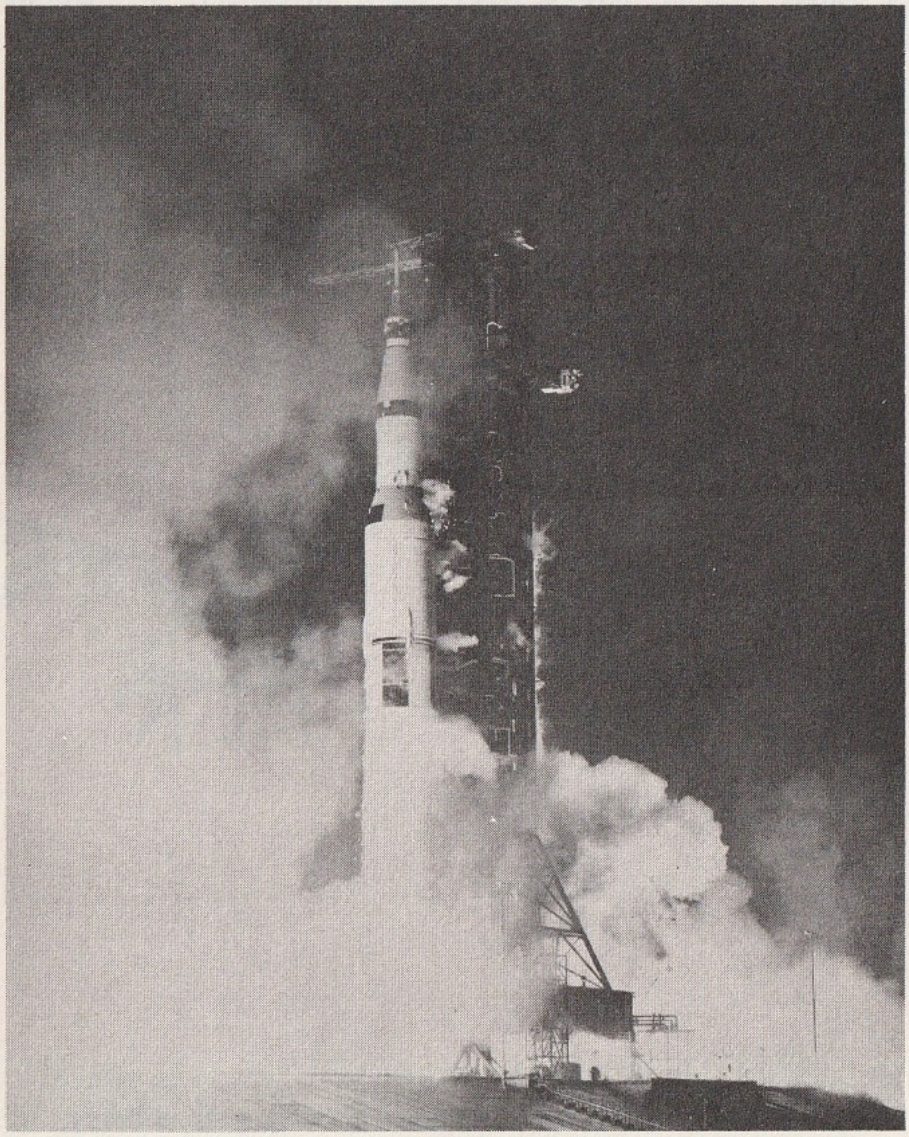
What We Hear

ONE OF THE PROBLEMS facing researchers into hearing is the fact that, while electronic instruments can measure the physical qualities of sound waves—their frequency, intensity, harmonic content and so on, there is no way of obtaining equally accurate measurements of hearing.

The perception of sounds takes place in the brain, yet we do not normally "hear" sounds inside our head. Instead, we "hear" them as coming

from some place outside our body. We know that our auditory nerve and brain activity is electrical, and that sounds are fluctuations of air pressure. Therefore we do not really hear the "sounds" themselves, but patterns of electrical impulses that *represent* the sound waves in the air.

The "hearing" takes place only in the mind of the listener, and the only way we can find out what someone hears is by asking him to describe it. Obviously we can't formulate any laws about human hearing on the basis of experiments involving only three or four people. The same tests must be conducted on hundreds or thousands of people, and the test



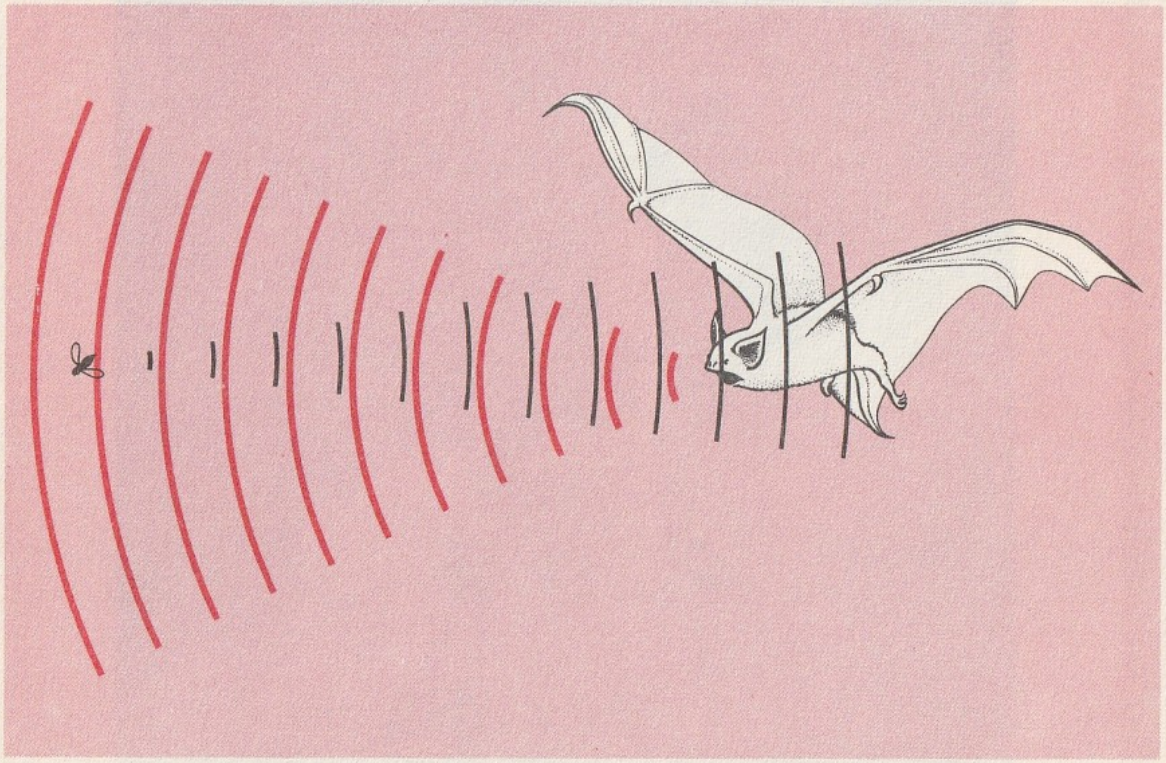
The Saturn V rocket that propels Apollo astronauts to the moon produces sound waves that can be heard for miles in all directions. This was the Cape Kennedy lift-off of Apollo 12.

results must be averaged out statistically, before we can be confident that "most" people respond in certain ways to certain patterns of sound waves.

All sounds are air pressure variations, but many pressure variations are *not* audible to us. For instance, when we ride in an elevator, the change in air pressure with changing altitude is often felt as an uncomfortable pressure in the ears—*not* as a sound. The change, although of appreciable intensity, is not audible because it occurs too slowly.

On the other hand, it is an established fact that bats, which are indeed as blind as they are reputed to be, navigate in total darkness by means of a "sonar" sound system that is too *high* in frequency for us to hear. The bat's radar chirps, which have been measured at around 30,000 cycles, are undoubtedly sounds because the bats can hear them. But our hearing functions in a much lower range of frequencies.

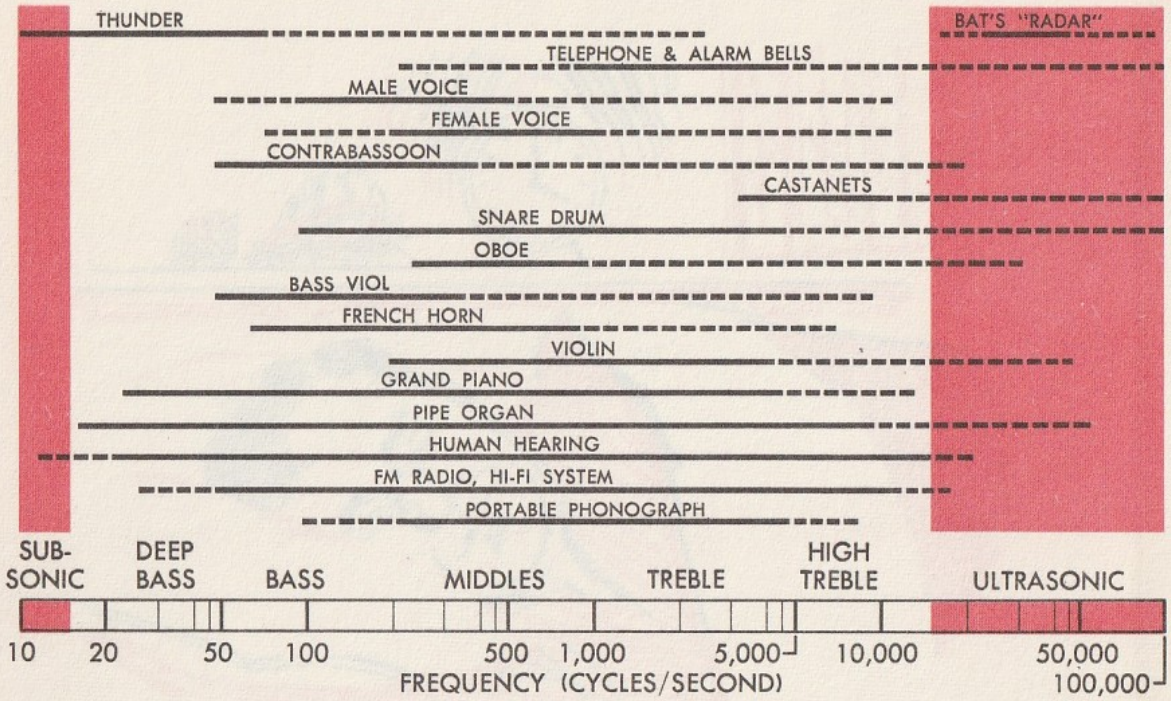
It is possible to establish rather loose frequency limits to human hearing.



A bat avoids obstacles and homes in on its prey, a flying insect, by emitting a series of extremely high-pitched chirps and then listening to the pattern of their returning echoes, a form of sonar found in nature.

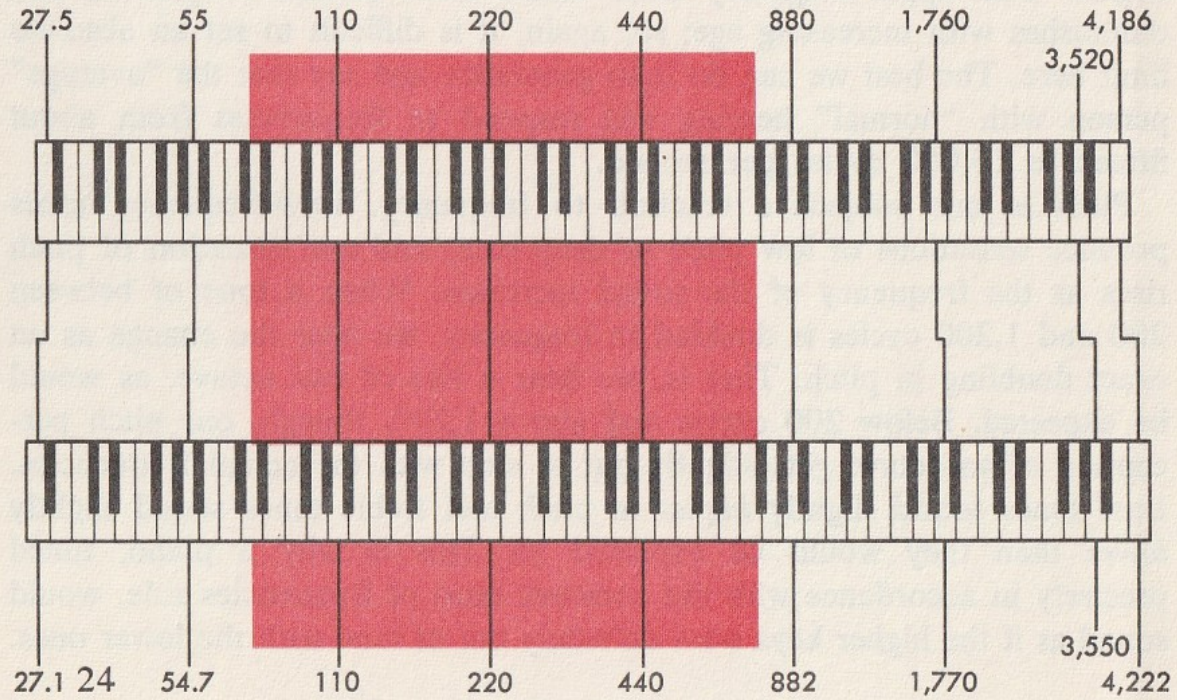
The lowest audible frequencies are of about fifteen cycles per second—they are heard as a deep rumble, and also *felt* as pulsations over the whole body; so it is hard to say just where feeling ends and hearing begins. The upper-frequency limit varies from person to person, and diminishes with increasing age; so, again, it is difficult to set an absolute limit here. The best we can do is to generalize and say that the "average" person with "normal" hearing will respond to frequencies from about fifteen to 15,000 cycles per second.

Pitch is our subjective reaction to frequency. Low-frequency tones produce sensations of low pitch or deep bass, and our sensation of pitch rises as the frequency of the sound increases. When a tone of between 200 and 1,200 cycles is doubled in frequency, we *hear* the change as an exact doubling in pitch. That is, we hear a rise of one octave, as would be expected. Below 200 cycles and above 1,200, though, our pitch perception of an octave gets slightly out of step with the actual frequencies. Bass tones sound slightly *higher* in pitch and treble tones sound slightly *lower* than they would be expected to. This is why a piano, tuned precisely in accordance with the constant ratio of frequencies rule, would sound as if the higher keys were definitely out of tune with the lower ones.



This chart shows the frequency range, in cycles per second, of some familiar sounds. The dotted lines indicate the regions in which our response to the sound energy is weak.

The upper keyboard shows the equal-tempered frequencies for some of the tones, based on middle A=440 cycles per sec. The lower keyboard shows how a piano tuner adjusts the frequencies so that the piano will "sound right" to the ear when compositions involving the whole keyboard are played. Within the shaded range, both tunings coincide.



Loudness or *volume* is the subjective equivalent of intensity. The more intense the sound, the louder we hear it, but again, there is no simple correlation between the intensity of a sound and the loudness with which we hear it. The constant-ratio rule holds here, too, but the ratios differ from those of pitch perception.

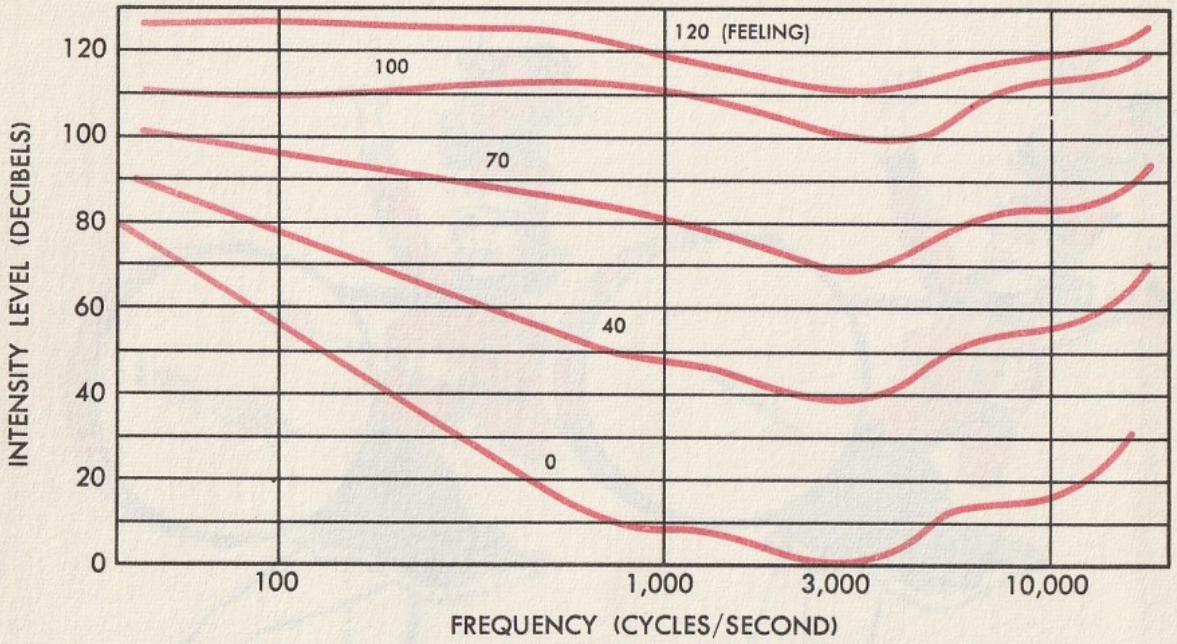
Increasing the intensity of a tone by a factor of ten makes it sound twice as loud as before, regardless of its original intensity. To double the loudness of a sound of one microbar pressure, we must increase its intensity to ten microbars. To double its loudness again, we must increase its intensity to 100 microbars, and to double its loudness again, we must increase its intensity to *1,000* microbars.

Acousticians have devised the *decibel* (db) scale convenient for expressing intensity changes. The sound's original volume, whatever this may have been, is usually taken as the reference point, or point of zero-db change. Changes above or below this reference point are ex-

pressed as plus-db or minus-db values, to show whether volume was gained (+) or lost (—). If we take as our O-db point the softest sound we can hear, we have a convenient scale for measuring the audibility of any sound in terms of decibels above our *threshold* of hearing.

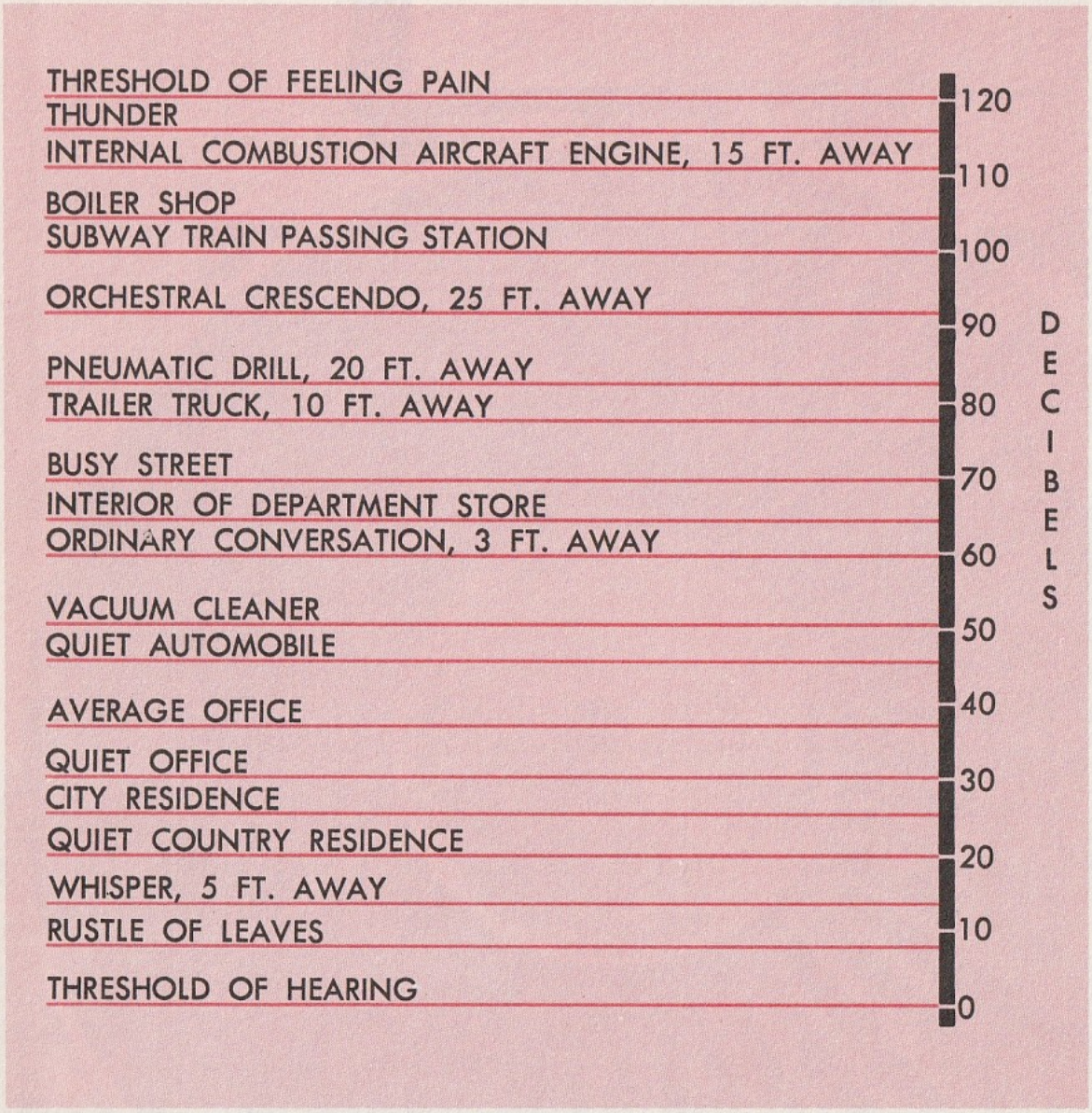
Our ears will withstand sound waves that are strong enough to vibrate our whole body, but for practical purposes we consider as our upper limit of loudness that point where sounds create tickling or painful sensations in the ears. This *threshold of feeling* is over a million million times more intense than the softest sound we can hear.

Another dramatic aspect of hearing is the ear's response to different frequencies. When dealing with very weak sounds, the ear is most responsive to those of a frequency of about 3,000 cycles per second. At the threshold of hearing, other frequencies need to be progressively louder if we are to hear them at all. But at very high intensities, all frequencies of equal strength are *heard* as having approximately equal loudness. At



The way in which we perceive loudness depends on pitch as well as sound energy. The bottom curve shows the sound energy needed for bare audibility at different frequencies. This shows that we normally hear a ten-decibel sound at 1,000 cycles as loudly as a sixty-db sound at 100 cycles. The upper curves show the smoothing effect of the ears' built-in "volume control"; but *all* curves show that we are most sensitive to sounds around 3,000 cycles.

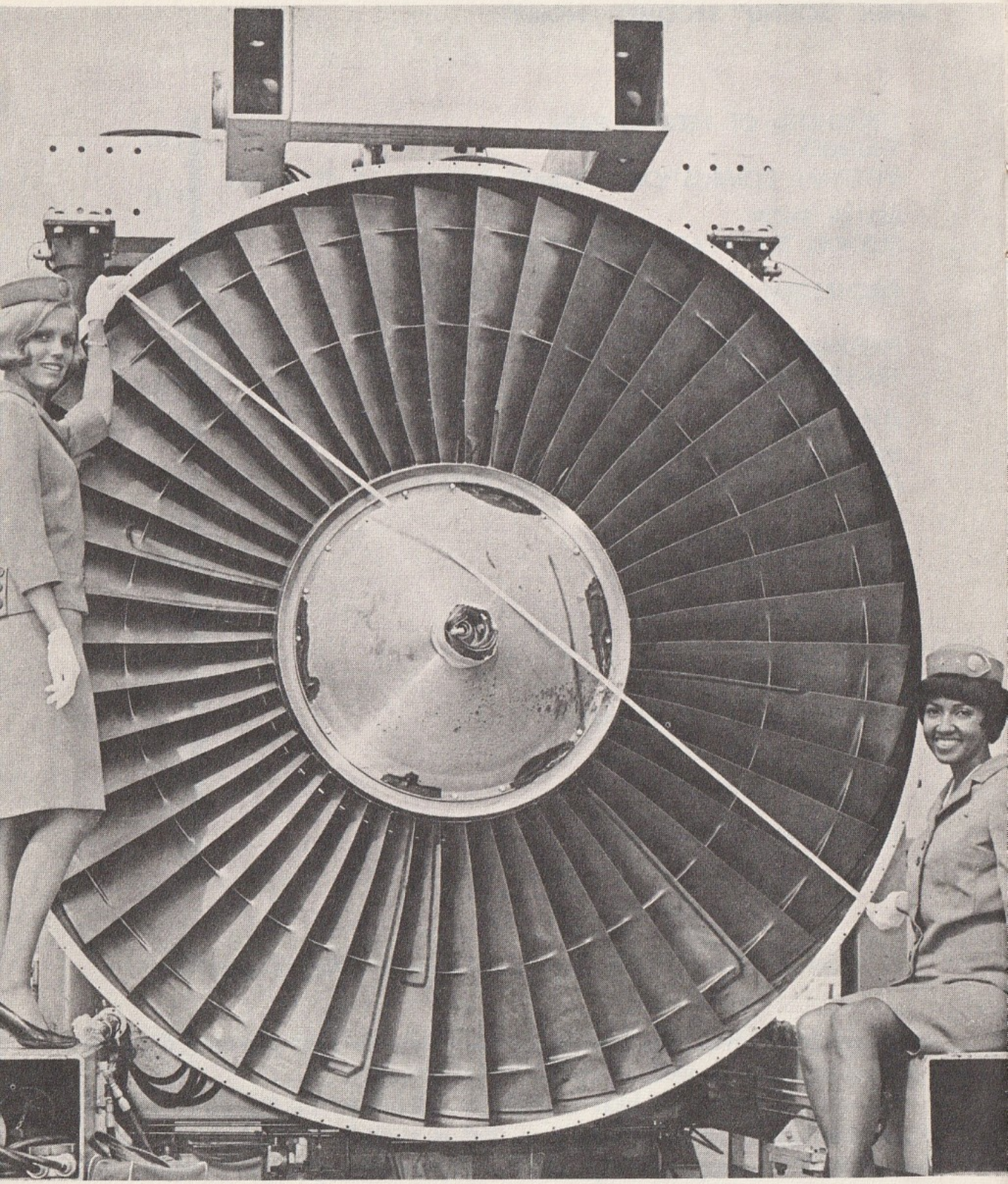
WHEN "SOUND" BECOMES "NOISE"



Zero on this scale is equal to a sound pressure of 0.0002 microbars.

lower intensity levels, the loudness with which we hear a sound depends on its frequency as well as on its actual intensity.

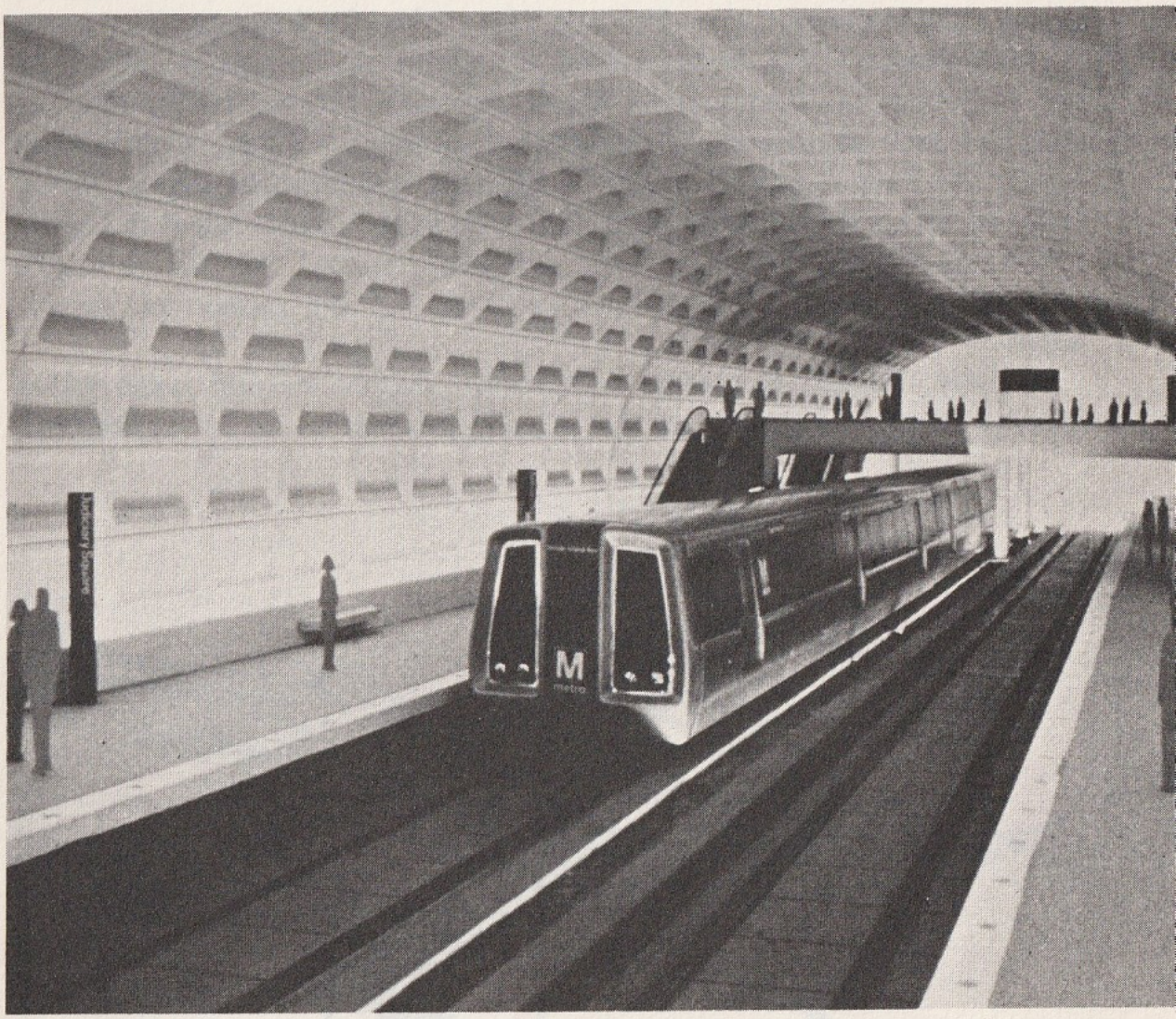
The way in which we hear a sound is influenced by the other sounds accompanying it, too. A single tone that is audible by itself can become *inaudible* if accompanied by another much louder tone, because the louder one will reduce the ear's acuity to the point where the softer tone drops below the threshold of hearing.



Talk about decibels! This is the eight-foot-diameter inlet of the engine of today's 747 superjet, producing 42,000 pounds of thrust.

Our ears' reaction to sound waves may seem rather disorderly, but we do recognize and appreciate orderliness in sounds. We may not hear all the frequencies in a complex sound in their proper relationship to one another, but we do hear most of them in some way, and we respond *emotionally* to the relationships we hear.

When we say that two notes are "in tune" or "out of tune", we are making a judgment based on our reaction to their relationship. Obviously, we are not mentally measuring and comparing their frequencies, because if we were, there would always be a direct correlation between fre-



Special soundproof walls are a feature of the new subway system due to be completed in Washington, D.C., in 1975.

quency and perceived pitch. What we *are* doing is reacting emotionally to the relationships the two frequencies establish in our hearing mechanism.

Certain combinations of tones strike us as being distinctly pleasant or "right", while other combinations sound unpleasant and very definitely "wrong". We use the terms *concord* or *consonance* to describe a pleasant combination, and we call an unpleasant combination of tones a *discord* or *dissonance.* In general, we experience pleasant sensations from the combination of tones whose frequencies are in simple mathematical ratio.

The octave—a combination in which one tone sounds twice as high in pitch as the other—is the most right-sounding combination. An octave is produced by two tones of which one's frequency is just twice that of the other—a frequency ratio of 2:1. The next most consonant combination is the 3:2 frequency ratio—300 and 200 cycles, for instance. The larger the two numbers that must be used to express the frequency ratios, the less consonant the combination. When the ratios become purely random, and lose their mathematical relationship entirely, we hear a discordant sound. As long as one frequency in the tone maintains its regular vibrations, we will still hear some quality of pitch in the sound. But if the entire sound consists of random impulses, irregularly spaced, we will be unable to detect any pitch at all. At this point we say the sound has become *noise.*

Actually, we use the terms consonance, dissonance and noise rather loosely, referring to anything that sounds pleasant to us as consonance,

Lacaro

and calling unpleasant sounds dissonances or noises, depending upon their degree of "insult to the ear".

Our reaction to a sound is influenced by its loudness, too. One that seems quite tolerable to us at low volume can set our teeth on edge when it is very loud. One reason is that the ear, like any other mechanical device, starts to *overload* when driven near its upper limit, and the overloading adds to the sound a whole new set of harmonics not present in the original sound.

Hearing with Both Ears

THUS FAR, WE HAVE CONSIDERED each of our ears as an independent instrument. But there are many ways in which our ears behave as though they were connected. If we feed one tone to one ear and another tone of widely different frequency to the other, their loudness will accumulate just as they do when both are heard through one ear. On the other hand, if the two ears are fed separate tones that would normally cause masking effects, practically no masking occurs; so two-eared hearing is not *quite* the same as one-eared hearing.

We can hear practically all of the physical aspects of a sound—its loudness and frequency content—with one ear, so why use two? Simply because one ear doesn't tell us all we need to know about the sound.

To return to the sharp-eared caveman for a moment: he has just heard a sound that he identifies as a snapping twig. He knows that something is nearby, but with bushes all around him, the twig-snapper could be in front of him, behind him, or off to either side of him. Which way should he run in order to avoid losing an arm or two to a hungry cat? In other words, where did the sound come from? One ear won't tell him, but two ears will.

The "location" of sounds at some point outside our head is entirely a function of listening with both ears. When we block one ear, we lose all sensation of the direction from which sounds are coming, and auditory perception of the size of our surroundings is lost. Compared with binaural (two-eared) hearing, monaural (one-eared) hearing is confused, unfocused and remote. And with one ear only, we lose our normal ability to "tune in" on a certain sound, to the exclusion of other competing, irrelevant sounds. This is aptly illustrated by the so-called *cocktail party effect.*

Cocktail parties are usually noisy. Everybody talks at once, and a little too loudly; yet, although all the resulting air disturbances are about equally

Science Bulletin
Prepared by SCIENCE SERVICE

ROCK MUSIC

In Bucks County, Pennsylvania, there are some rocks that ring when you tap them with a hammer.

All materials are capable of producing some kind of tone under proper conditions, but the rocks in Bucks County have an audible tone of unusual duration and frequency for rock material.

Dr. John F. Gibbons II of Rutgers University and Steven Schlossman, a graduate student at the University of Massachusetts, believe they have found the reason for the peculiar musical talent of the Bucks County rocks.

The rocks, the researchers found, are under abnormal stress from slow mineralogical changes, which are in turn the result of unusual environmental conditions that combine to prevent the rocks from retaining moisture and to subject them to wide temperature variations.

In addition, the geologists report, the rocks are amazingly elastic. Since elastic strain applied to a material can change its frequency, the unusual stress on the rocks in Bucks County could be the source of the observed change in their characteristic tone.

TREES ACT AS BUFFER

Noise levels near busy highways and heavily used airports are sometimes high enough to damage the health of people living nearby.

Research by the Florida State Extension Service shows

that trees and shrubs can be an effective buffer, says FSES Forester Tony Jensen.

Jensen says many factors affect the noise-reducing efficacy of the trees. These include size, position and density of the trees; wind, moisture and temperature, and relative vertical position of the noise source and the trees. If the noise source is lower than the buffer zone of trees, for example, the trees are more effective as noise reducers.

Jensen says a 100-foot width of trees along a highway will reduce noise levels eight to eleven per cent and that greater widths will provide proportionately greater reduction.

DETECTING STRESS

Engineers at North American Rockwell's Space Division in Downey, California, are developing ultrasensitive, nondestruction techniques for spotting potential airplane structural problems before the breaking point occurs.

One example is a listening device that can detect metal stress sounds inaudible to the human ear. Columbium and titanium metals for possible use in the space shuttle or in advanced aircraft are being stress-tested to establish patterns of intensity for these trouble sounds.

Other techniques include electronic devices such as tiny glass fibres used to conduct images of inaccessible areas on the craft.

Such instruments aboard a craft could detect deterioration before any structural failure occurs, says Bastian Hello, space division vice president.

LASER-PRODUCED SOUND

Laser light can be used to produce sound waves in solid bodies; the light reacts with structural characteristics of the solid in a variety of ways to produce vibrations.

Dr. D. C. Auth of the University of Washington at Seattle reports a new method for using laser light to produce sound at microwave frequencies. The new method differs from the previous one for this frequency range by using two light pulses of identical rather than of different frequencies and by producing much higher power in the solid.

Two identical light pulses of about ten to eleven seconds' duration are sent into an absorbing solid at an angle to each other. At the points in the solid where the waves reinforce each other, they cause intense heating; the heat causes large pressure differences.

As the light waves beat against each other in the solid, the pressure at any point rises and falls periodically, generating two acoustical waves running in opposite directions. The frequency of the sound can be varied by changing the angle between the light beams as they hit the solid.

MACHINE FOR THE MUTE AND DEAF

The deaf and the mute can now communicate with others over the telephone with an invention by Cybernetics Research Institute, Washington, D. C. The device, called Cyberphone, is a portable telephone communication system that fits inside an attache case. It consists of a panel of buttons and lights with the forty-nine letters, symbols and numbers found on a typewriter. There is also a place to hold a telephone receiver.

To use the machine, the sender places the receiver in the set and spells out his message using a keyboard push-button system. It is transmitted via pulse-coded signals through the telephone system to another Cyberphone set, where it is either read directly from flashing lights on the panel, typed out on a typewriter or recorded on tape for playback at a later time.

MIDDLE EAR EFFUSION

Chronic middle ear disease with effusion is common in

children between the ages of three and ten. With the condition, fluid collects behind the eardrum where it can remain for a long time, causing the children to become hard of hearing.

The cause of the disease, however, remains controversial. Reporting on a study of 123 cases, Dr. Raymond E. Jordan of Pittsburgh, Pennsylvania, advances the theory that chronic middle ear effusion is caused by the membranes of the nose, Eustachian tube and middle ear becoming sensitive or allergic. He explains that the sensitization or allergy of these areas can be caused by inhalants, food or bacteria. The area first swells, then fluid forms.

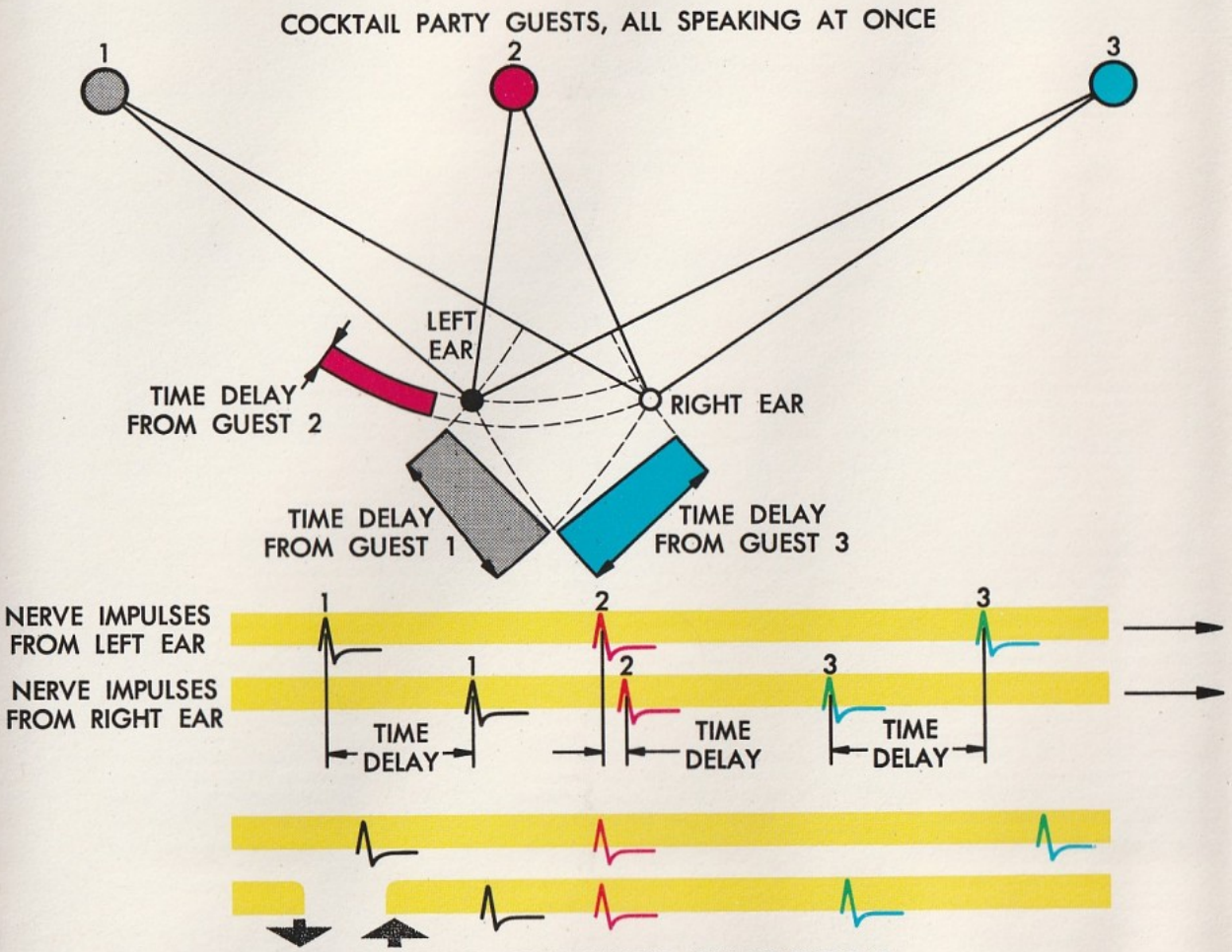
After the allergen has been identified, the most successful long-term treatment of these cases has occurred in those patients where the allergen was removed or treated with proper medication, Dr. Jordan says.

RESEARCH AT LOW MACH

Aeronautical engineers have indications from prior research that it is possible to operate an aircraft at lower than designed speeds, but slightly above the speed of sound, without producing sonic booms that disturb persons on the ground. However, atmospheric factors such as weather, temperature and air pressure are related to this phenomenon.

To investigate these parameters, engineers from the National Aeronautics and Space Administration's Langley Research Center at Hampton, Virginia, are conducting test flights at the Atomic Energy Commission's Nevada test site. Pilots are flying F-104's over a 1,500-foot-high tower instrumented with fifteen microphones. At the base of the tower, sixteen more microphones have been spaced in a horizontal straight line. These will be used to monitor the low intensity booms.

Pilots will fly the craft between Mach 1.05 and 1.3. These are threshold speeds at which the sonic boom cuts off or dissipates in the atmosphere.


COCKTAIL PARTY GUESTS, ALL SPEAKING AT ONCE
1
2
3
LEFT EAR
RIGHT EAR
TIME DELAY FROM GUEST 2
TIME DELAY FROM GUEST 1
TIME DELAY FROM GUEST 3
NERVE IMPULSES FROM LEFT EAR
NERVE IMPULSES FROM RIGHT EAR
TIME DELAY
TIME DELAY
TIME DELAY
TO "FOCUS" ON SPEAKER 2 IT IS CONJECTURED THAT RIGHT-EAR IMPULSES ARE ROUTED THROUGH LATERAL NERVES UNTIL DELAYED ENOUGH TO SYNCHRONIZE WITH LEFT-EAR IMPULSES FROM SPEAKER 2.
8. THE COCKTAIL PARTY EFFECT

This diagram illustrates how we might use our auditory system's cross-connections to "focus" on a desired sound while in a noisy place.

intense, we are easily able to pick one voice from amidst the hubbub, simply by concentrating on that voice.

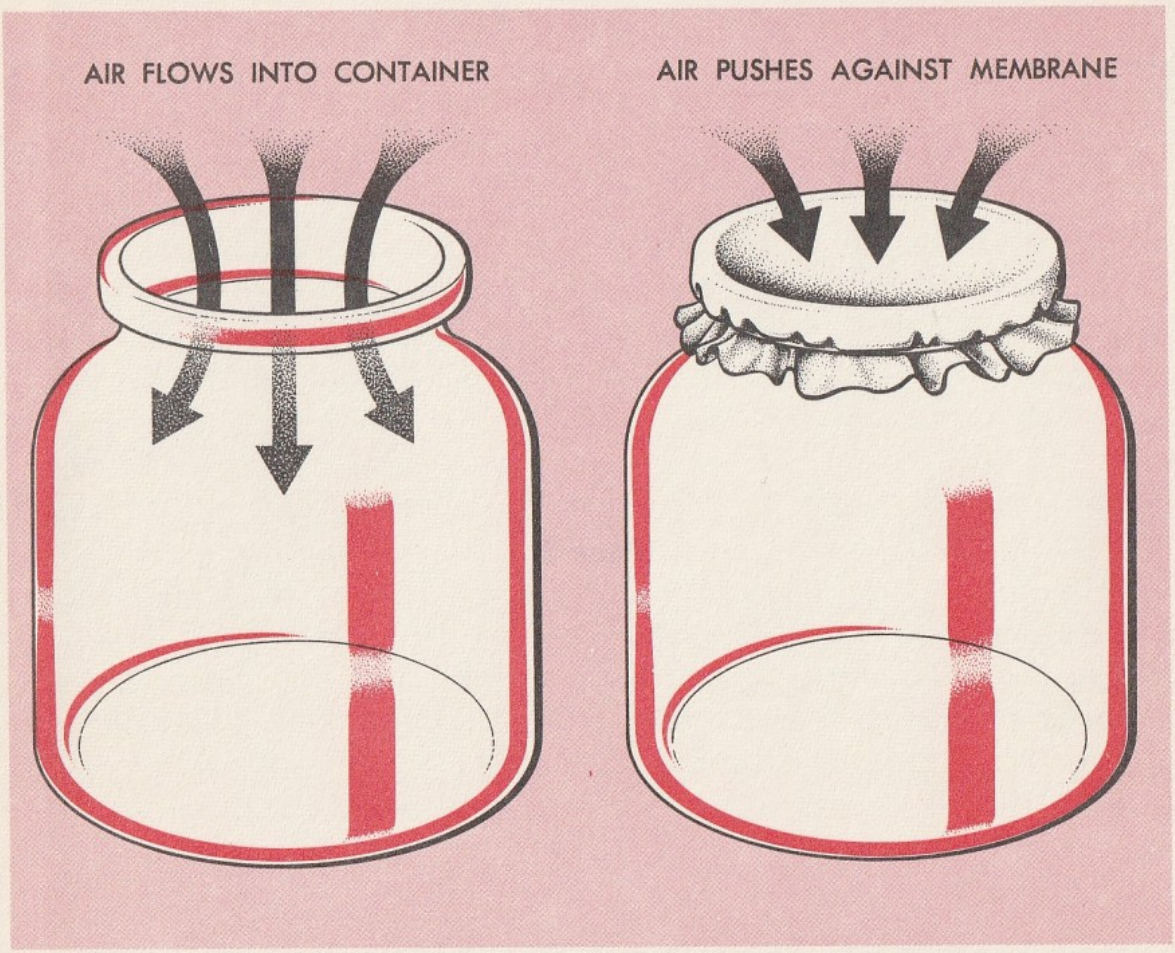
Recognition plays some part in this; as soon as we hear a word or two, we can generally get the gist of a conversation. But when we block one ear, so that we are forced to rely entirely on recognition patterns, everything becomes a confused babble of chatter, and listening to a single

voice becomes difficult. This ability to "focus" on one sound, to the exclusion of all others, is another function of two-eared hearing.

How We Hear

THE BRAIN ITSELF IS deaf, dumb, blind, and almost totally insensitive to everything that goes on around us. It is encased in a pitch-dark, sealed container that protects it from damage and at the same time isolates it from everything outside it. All the information it gets about the world beyond its sealed container must be piped into it from our sense organs, our eyes, nose, skin, palate and ears. And since all of the brain's functions are performed by shunting tiny electrical impulses from one brain cell to another, all the sensory impressions it works with must be presented to it in this form: as a series of single electrical impulses of identical shape and intensity.

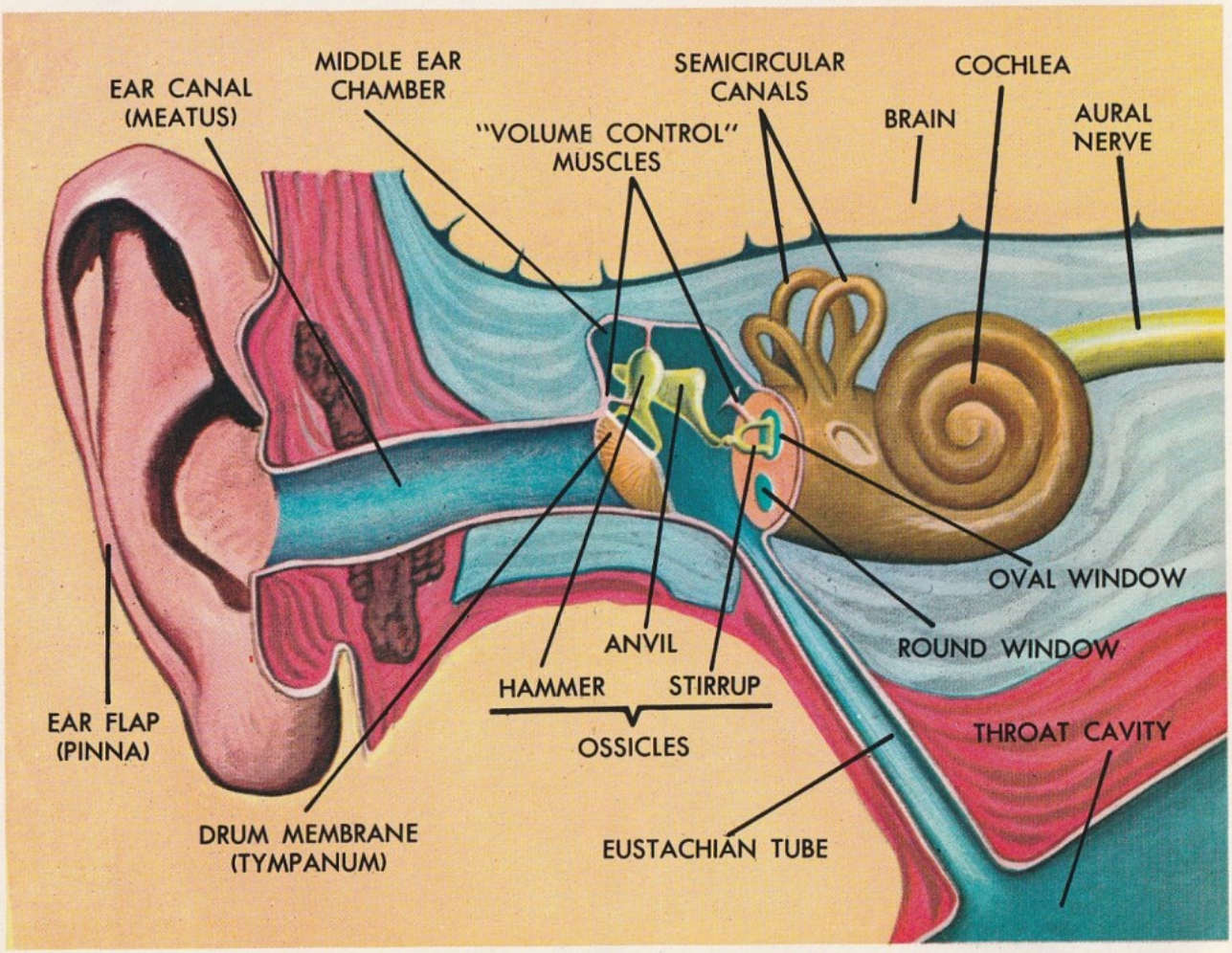
Thus the ears, like every other sense organ, are required to convert the outside stimulus—the air pressure fluctuations—into various patterns of these impulses that convey all the information we can hear about the sound's intensity, harmonic content, frequency and direction.



A flexible membrane sealing off an enclosed container will convert pressure changes in the outside air into physical motion of the membrane. An increase will push the membrane in; a decrease will allow it to be pushed outward.

Three steps are required to do this. First, we must detect the pressure changes in the air and convert them to vibrations. Secondly, the feeble, air-induced vibrations must be converted into stronger vibrations that are capable of moving the solid parts of our hearing mechanism. And, finally, we must convert these vibrations into the necessary electrical impulses, retaining as much as we can of the sound's individual qualities. The three sections of the ear that accomplish this are called the *outer, middle* and *inner* ear.

Air always tries to maintain uniform pressure. If the pressure of the air outside a container is different from that inside it, some air will attempt to flow from the high-pressure area into the low-pressure area to equalize



6. CROSS SECTION OF THE HUMAN EAR

The middle ear chamber is kept at atmospheric pressure via the eustachian tube. Rapid variations in outer air pressure vibrate the eardrum membrane, the ossicles pass the vibrations to the cochlea, and the cochlea sends corresponding patterns of nerve impulses to the brain. The semicircular canals provide us with our sense of bodily orientation and balance.

the pressures. If the container is sealed, the air cannot flow into or out of it to maintain a balance against the outer air—but it will keep trying to. So if a hole in the container is covered with a thin, flexible membrane, any pressure difference will make this membrane bulge into or out of the container. This is how the ear's pressure-detection system works.

The middle ear is a chamber about the size of the first joint of your thumb, a hollow within the bone at the side of the skull. The air pressure

in this chamber is maintained at normal atmospheric pressure via a small duct, the *eustachian tube,* which opens into the back of our throat every time we swallow or yawn. That is why we do either of these things when we want to relieve the uncomfortable pressure in our ears caused by a change in altitude.

The outer ear, comprising the external flap or *pinna,* and the *ear canal,* connects the middle ear chamber with the outer air, and a flexible membrane, the eardrum or *tympanum,* prevents the free flow of air between the middle and other sections. Consequently, when the outer air pressure fluctuates too rapidly for us to keep the middle ear cavity at the same pressure, the resulting pressure differences force the eardrum to bulge in and out in accordance with the fluctuations.

Who Hear Better—Men or Women?

Women have better hearing than men. Surveys show that by the age of twenty women have a slight but statistically significant advantage over the opposite sex. Studies at the Hearing Research Laboratory at the University of Minnesota, for example, demonstrate that women's hearing is less affected by the roar and rumbling of low frequency noise. Women, moreover, appear to be more sensitive to high frequency sounds.

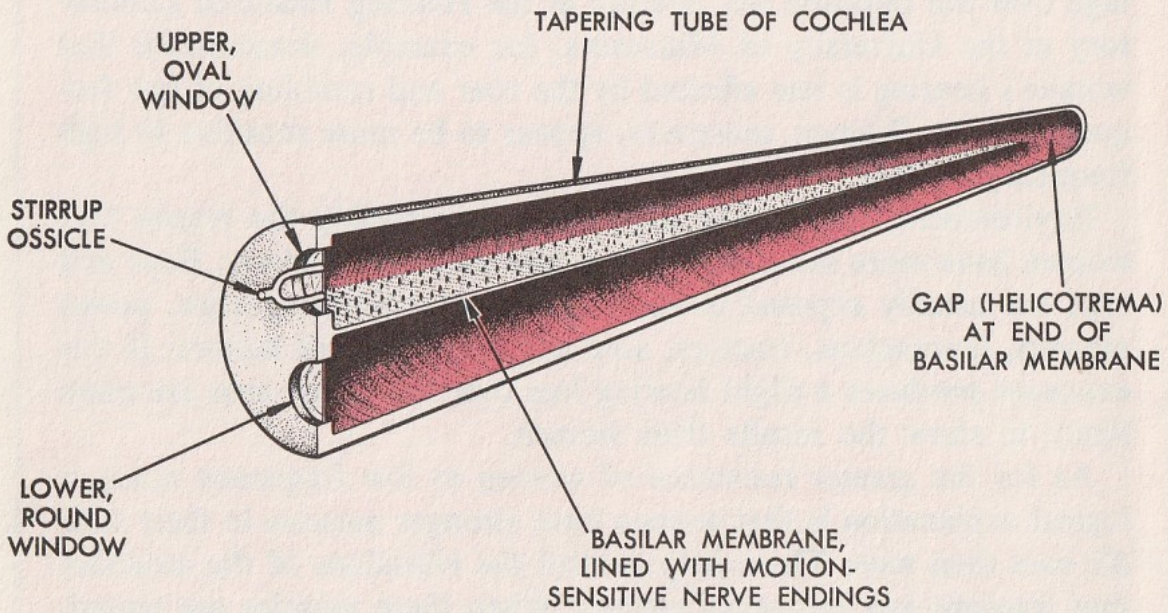
Environment, rather than physiology, is probably the reason that women have more sensitive hearing than men. One reason: Boys and men are usually exposed to more noise—explosions, gunfire, power mowers, firecrackers, tractors, auto engines, outboard motors. If this exposure produces a slight hearing loss over the years, men are more likely to show the results than women.

As for the greater resistance of women to low frequency noise, a logical explanation is that women have stronger muscles in their middle ears than men. These help control the vibrations of the structure that transmit low frequency sounds. When these muscles are tensed, the vibrations are lessened, diminishing the amount of sound that penetrates to the inner ear and then to the brain.

The inner ear (the *cochlea*), which converts vibrations to electrical impulses, is a cavity shaped like a coiled snail shell and filled with fluid. The eardrum movements are passed through a system of tiny levers, the *ossicles,* which convert the relatively large, feeble eardrum movements into much smaller but more powerful motions at the cochlea.

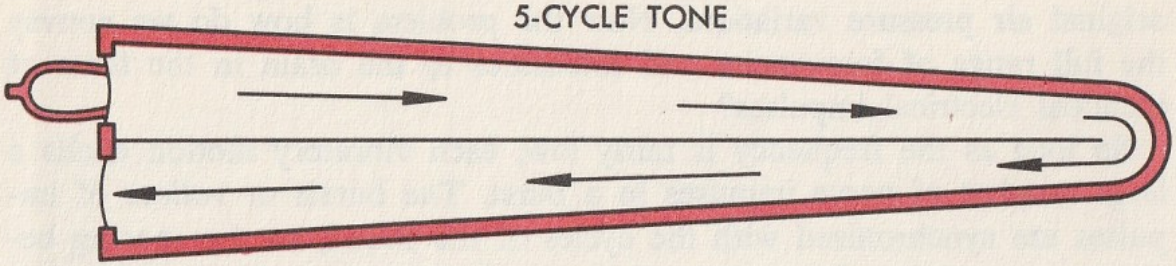
Two of these levers are fastened to the inside wall of the middle ear cavity by tiny muscles, which can inhibit the movement of the ossicles when tightened. These constitute our "automatic volume control" system. The muscles are actuated by a *reflex arc* circuit directly from the hearing nerve, so that when the nerve carries impulses corresponding to high intensity, the muscles tighten automatically.

The last ossicle in the chain, the *stirrup,* terminates in a small window membrane in the wall of the cochlea. The window allows the stirrup to pass pressure waves into the fluid in the cochlea; at the same time it prevents the escape of the cochlea fluid. But since the fluid is in a closed chamber and is uncompressible, another small window is located directly under the main one, to act as a "relief port" for the pressures transmitted to the fluid.


TAPERING TUBE OF COCHLEA
UPPER, OVAL WINDOW
STIRRUP OSSICLE
GAP (HELICOTREMA) AT END OF BASILAR MEMBRANE
LOWER, ROUND WINDOW
BASILAR MEMBRANE, LINED WITH MOTION-SENSITIVE NERVE ENDINGS

This cutaway view of the cochlea shows it uncoiled for purpose of illustration. The basilar membrane divides it in half for most of its length, leaving a small gap at the narrow end. The entire cochlea is filled with liquid, so any pressure changes imparted to the liquid via the upper, oval window must be relieved by displacements of the lower, round window.

5-CYCLE TONE



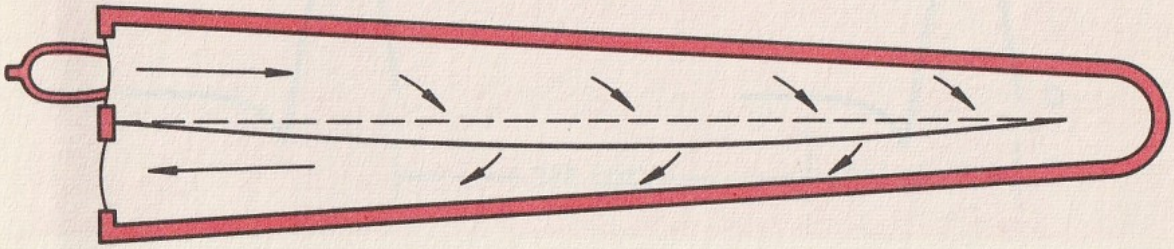
A subsonic tone vibrates so slowly that the liquid has time to shuttle back and forth around the gap (the helicotrema) at the end of the basilar membrane. The membrane itself is undisturbed.

Once the vibrations of the eardrum have been converted into back-and-forth movements of the cochlea fluid, they have to be converted into electrical impulses. This is the job of nerve endings, inside the cochlea, that respond to motion. Precisely *how* they make the conversion remains something of a puzzle to researchers; but it *is* known that they do.

The tapered cochlea tube is divided along most of its length by a thin wall, the *basilar membrane,* that separates the stirrup's *oval window* from the lower relief-port *round window*. The entire length of this membrane is lined with about 15,000 nerve endings, so arranged that bending of the membrane stimulates the cells to release their electrical impulses. These, then, are carried to the brain by the *auditory nerve bundle,* a solid cable comprising some 30,000 parallel nerve "lines".

The *basilar membrane* is not disturbed by vibrations of less than about fifteen cycles per second; but above that frequency, to the upper limit of our hearing, the cochlea sends out nerve impulses that correspond to the

30-CYCLE TONE



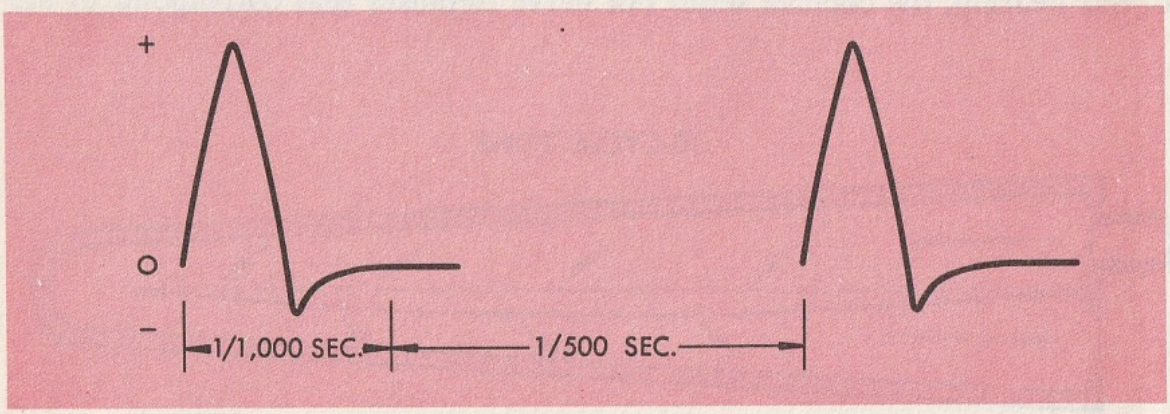
An audible tone of very low frequency vibrates too rapidly for the liquid to flow through the gap, so pressure changes are passed to the lower chamber by bending the basilar membrane up and down.

original air pressure variations. Now the problem is how do we convey the full range of frequencies and intensities to the brain in the form of identical electrical impulses?

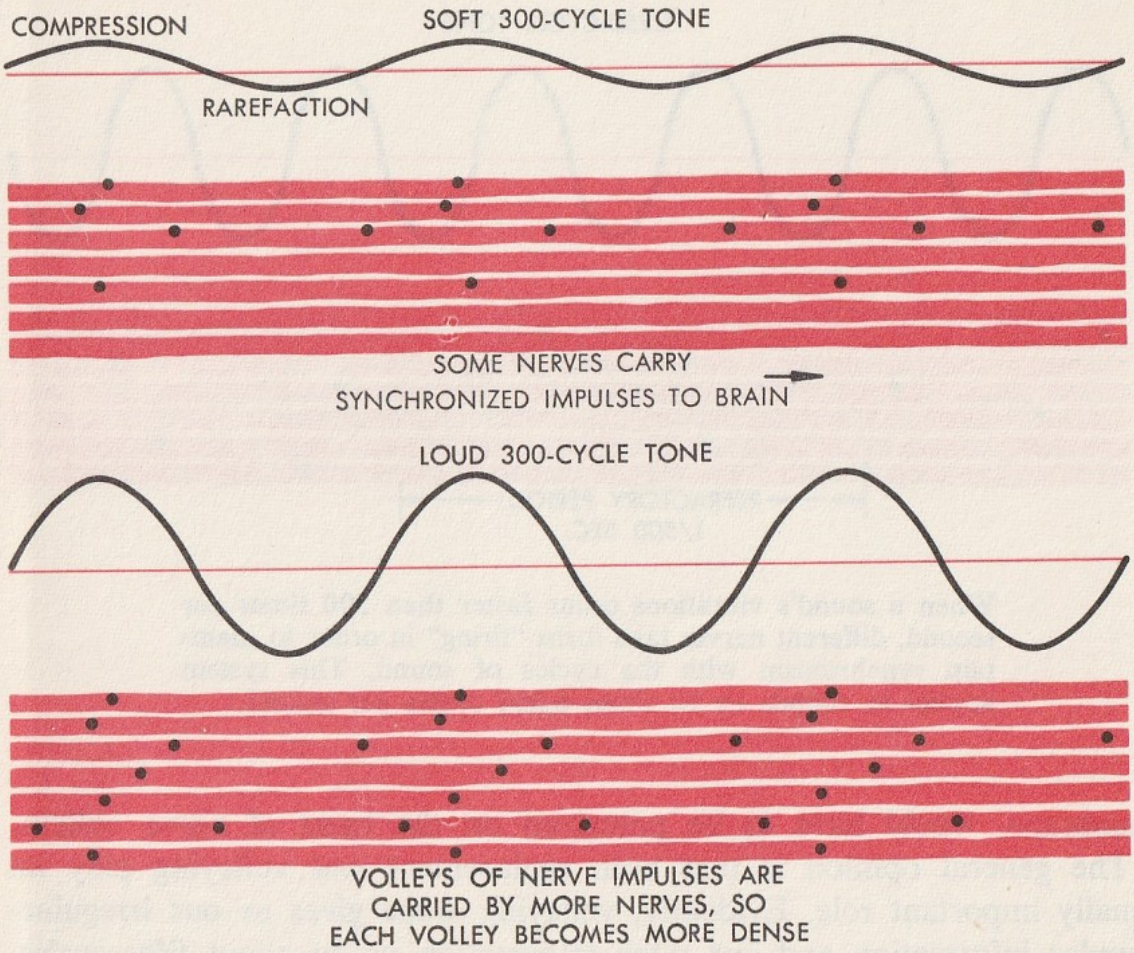
So long as the frequency is fairly low, each vibratory motion elicits a large number of nerve impulses in a burst. The bursts or *volleys* of impulses are synchronized with the cycles of the sound, so the spacing between successive volleys arriving at the brain can convey information about the frequency of the sound. And while the intensity of each electrical impulse cannot vary, the strength of each volley *can* be carried by the number of impulses released each time. Thus the brain can judge the intensity of the sound on the basis of the concentration of each synchronized volley of impulses.

This synchronized volleying has a limit, however. Each nerve cell, having passed an impulse, requires a brief recharging time or *refractory period* before it can pass another impulse. Since this refractory period lasts about 1/500 of a second, this means no individual nerve cell can stay synchronized with the cycles of a frequency higher than about 500 cycles. To overcome this limitation, different nerve cells take turns "firing", like the cylinders in a car engine.

Even this alternate-firing arrangement cannot maintain synchronism to the limit of our hearing range. Above about 6,000 cycles, the nerve impulses become random and lose their relationship to the sound. Therefore something else must convey high-frequency pitch information to the brain above this frequency.



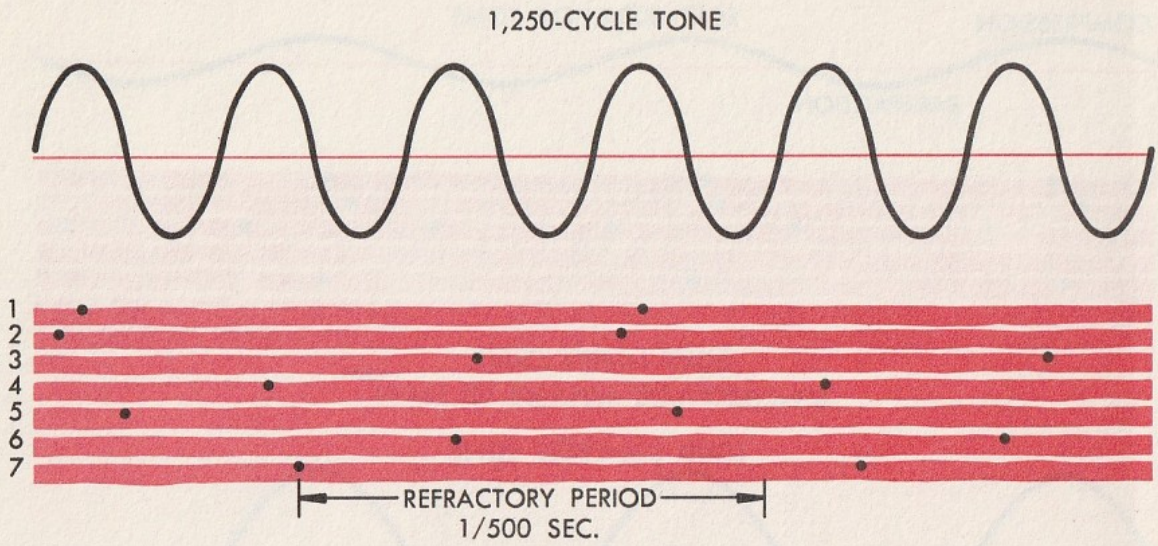
All sound information is conveyed to the brain via these impulses which are all of the same intensity and are limited to a 500-cycle repetition rate. The resting time of the nerve is known as the refractory period.



Nerve impulses passing through several nerves in response to a soft (*upper*) and a loud (*lower*) 300-cycle tone.

At frequencies higher than about fifty cycles, only a part of the basilar membrane vibrates—not the whole length. Different frequencies affect different parts. Low frequencies affect the part near the *helicotrema*—the gap at the end of the membrane near the apex of the cochlea; as the frequency rises, this vibration point moves along the basilar membrane toward the cochlear windows. So the brain presumably perceives pitch according to which part of the membrane is vibrating.

Researchers have argued for years as to which process—volleying or placement—is primarily responsible for our pitch perception. Placement explains our ability to hear frequencies higher than 6,000 cycles, and it also helps to explain why a loud tone masks a weaker one of similar frequency. But single impulses of sound, or irregularly spaced impulses that would not have time to elicit definite placement effects on the basilar



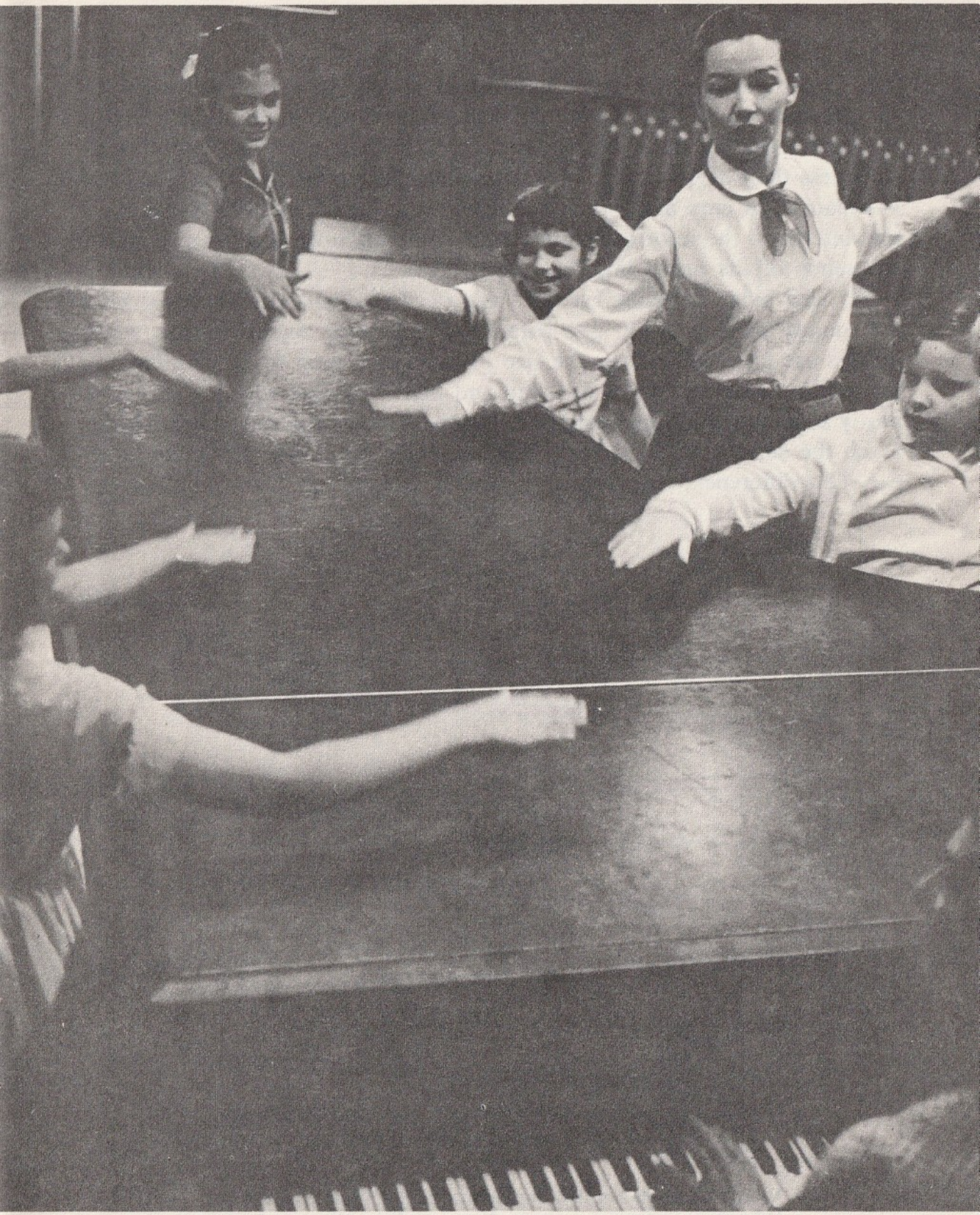
When a sound's vibrations occur faster than 500 times per second, different nerves take turns "firing" in order to maintain synchronism with the cycles of sound. This system applies to sounds up to about 6,000 cycles per second.

membrane, would have to be perceived on the basis of nerve volleys.

The general opinion is that both replacement *and* volleying play an equally important role. Evidently, volleying alone gives us our irregular-impulse information and our pitch information up to about fifty cycles. Volleying and placement combine to cover the range up to around 6,000 cycles, while placement alone takes over from there up to our upper limit of hearing.

Within the range where placement and volleying function together, we probably "select" whichever best conveys the information we desire about the sound. It is easy to see how we might sense pitch from the stimulation of a specific place on the basilar membrane, but it is less easy to understand how we could do it by "counting" volleys of nerve impulses that are rolling in at a rate of several thousand per second. The brain does, however, seem to be well equipped for dealing with such very small units of time.

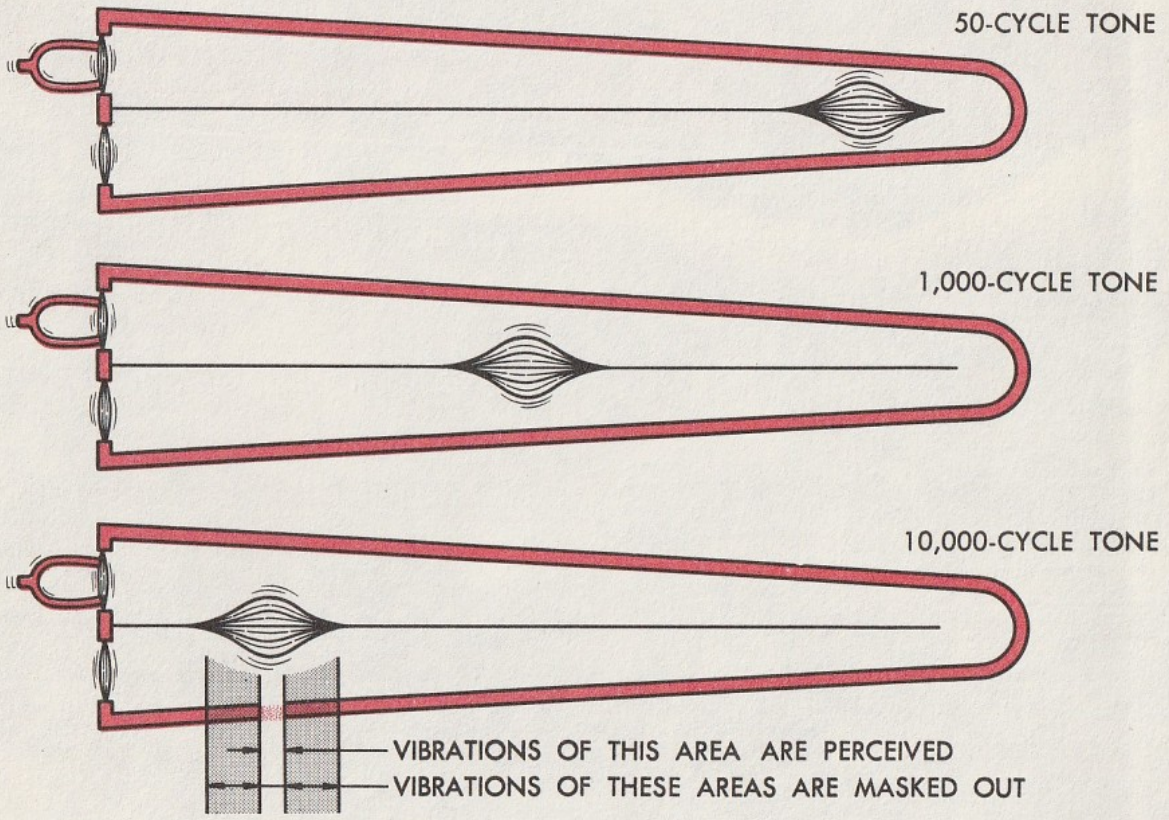
Much of our perception of space and direction involves split-second, unconscious recognition of the differences between the arrival times of sound waves at our two ears. All sounds take a definite period of time to travel from one place to another. If a sound originates from a point to one side of our head, each of its pressure waves will pass the closer ear a fraction of a second before it passes the other, more distant ear.



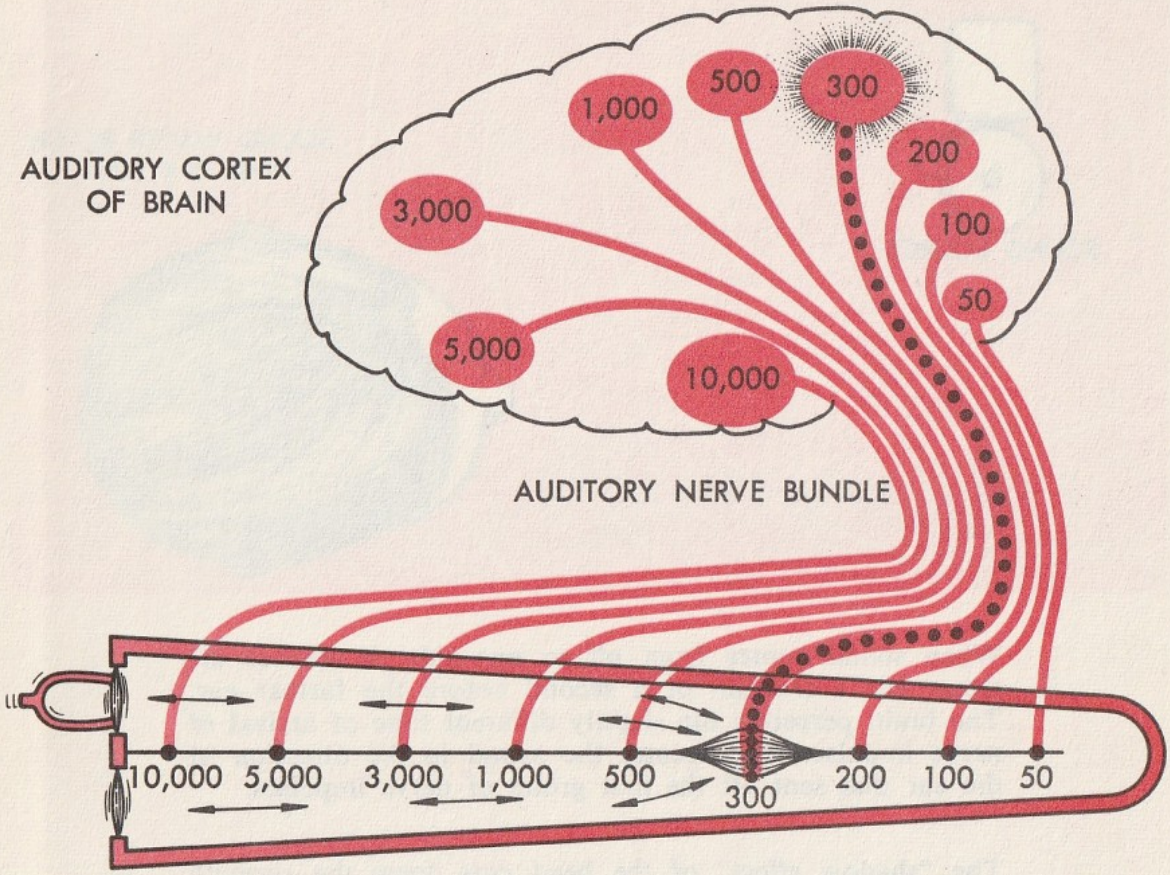
Deaf children are taught to hold their hands close enough to a piano so they may be able to feel its vibrations.

The nerve impulses travel at a constant speed, so the first ear to get the pressure waves will get its nerve impulses to the brain slightly before the corresponding impulses arrive from the other ear. The delay is always less than one-thousandth of a second and sometimes very much less —because the ears are less than a foot apart—yet the brain observes it and interprets the information in terms of direction on the basis of which ear sends off its nerve impulses first.

We also judge direction on the basis of the *volume* difference between the sounds arriving at our two ears. High-frequency sounds, whose wavelengths are far smaller than the size of our head, tend to be absorbed by the surface irregularities of our skin and hair. Middle-frequency tones are partly absorbed and partly reflected, but the effect is the same: most waves reach the ear that's facing them more strongly than they reach the other ear. This difference, too, gives us a clue to the position of a sound source.



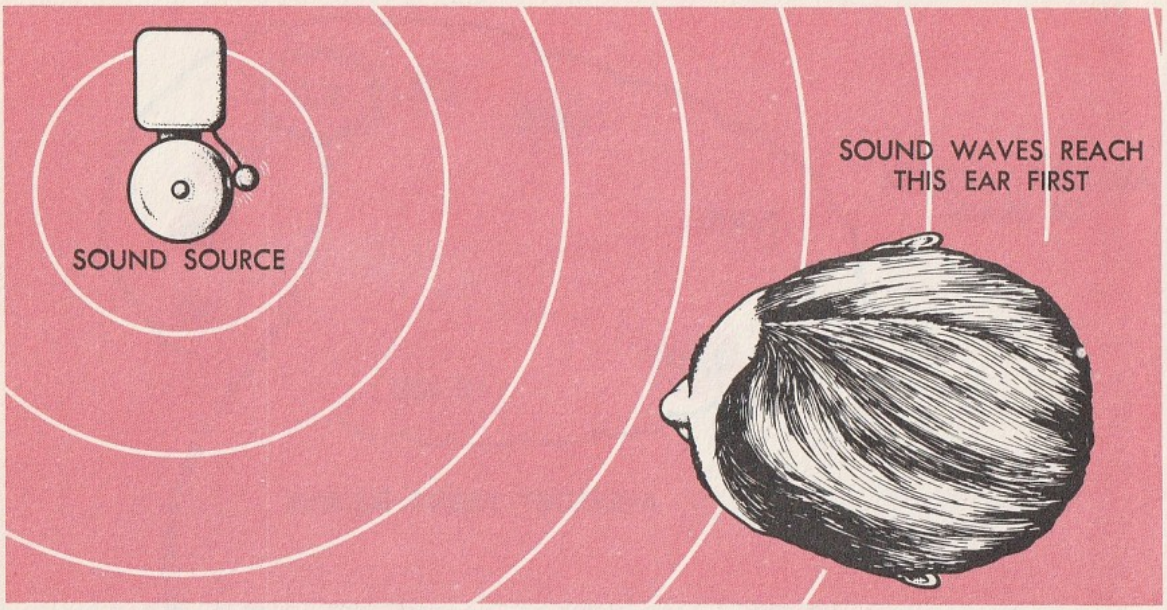
Vibration of the basilar membrane at different frequencies. Vibrations extend for some distance along the membrane, but some "sharpening" process evidently makes us attribute the vibrations to the middle of the affected area.



This diagram shows one way in which pitch information may be carried to the brain. According to one theory, vibration of different places on the basilar membrane stimulates different places in the brain's auditory cortex.

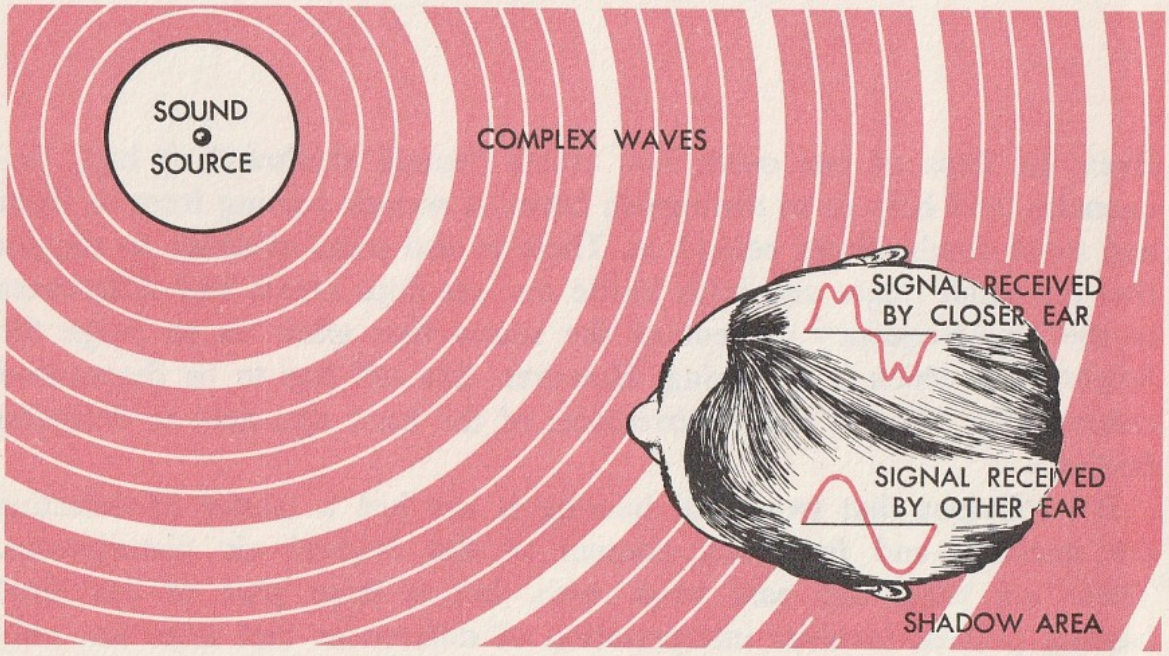
Even the flaps of our outer ears create "sound shadows" at high frequencies, and help us to distinguish between sounds coming from in front and those coming from behind us. There is also some evidence to suggest that the small ridges and folds inside our ear flaps create tiny differences in the high-frequency content of the sound that allow us to judge the *height* from which it is coming. However, this still has to be determined conclusively. Finally, small movements of the head also help in direction finding.

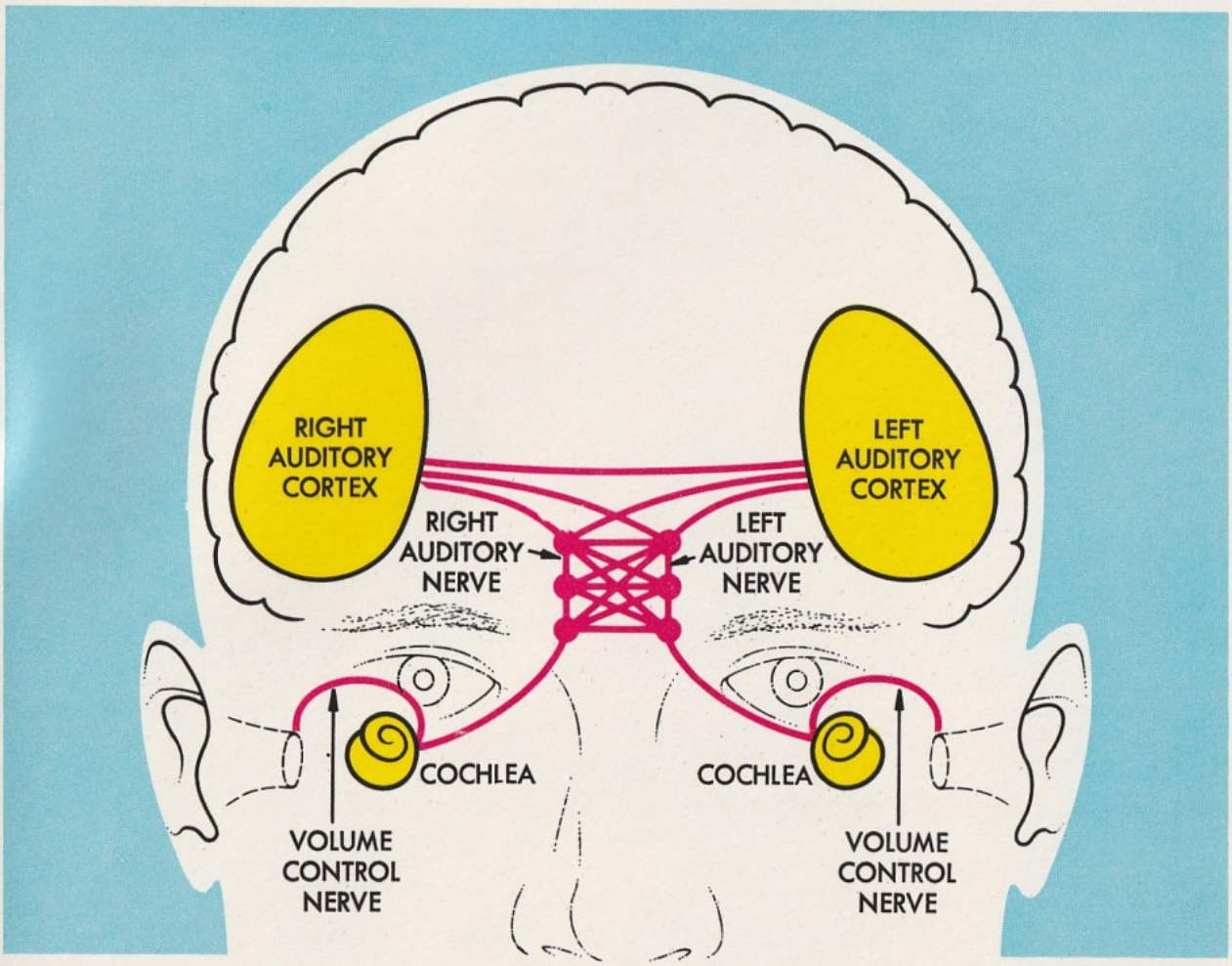
It is obvious that two-eared hearing is not just a matter of detecting the intensity and frequency content of the original air disturbances. These are what our ears work with, but a large part of our total hearing process involves interpretation of differences that arise not only



When sound comes from off to one side, it reaches the closer ear a fraction of a second before the farther ear. The brain perceives the slightly different time of arrival of nerve impulses, and locates the sound in the direction of the ear that sent off the first group of nerve impulses.

The "shadow effect" of the head cuts down the strength of the high-frequency overtones reaching the more distant ear, and the brain interprets the difference in overtone content as directionality, locating the sound toward the side that senses the most overtones.





7. AUDITORY NERVE SYSTEM

Some of the assumed interconnections between the ears, the brain, and the auditory nerves are shown here. A few of the nerves probably carry impulses from the brain back to the hearing system to operate the "volume control" muscles and to keep most of the cross-connections normally closed off.

from the original air disturbances themselves but from the way our two ears receive them. A simple time difference, from a single sound source, gives us the sensation of direction. Yet, so well does our "aural comparison system" function, that the receipt of a complex medley of direct and reverberated sounds results not in confusion but rather in a sense of "spaciousness" that comes from an awareness of sound in depth.

Some of this remarkably acute comparison process probably takes place in the brain stem where the signals are brought together. Each ear first

feeds its own auditory cortex located on the same side of the brain. There are many *cross*-connections between the two auditory channels, at several points along their length.

If all of these cross-connections were functioning all the time, the groups of nerve impulses from each cochlea would get hopelessly mixed up before they got to the brain, and it would be difficult to tell from which ear different impulses had come. Evidently, though, most of the cross-connections are not established as "through circuits" most of the time, but are rather like telephone lines—all there all the time, but only a few in use at any one time. The others are kept closed off by *inhibiting* impulses sent out from the brain *back* to the hearing system.

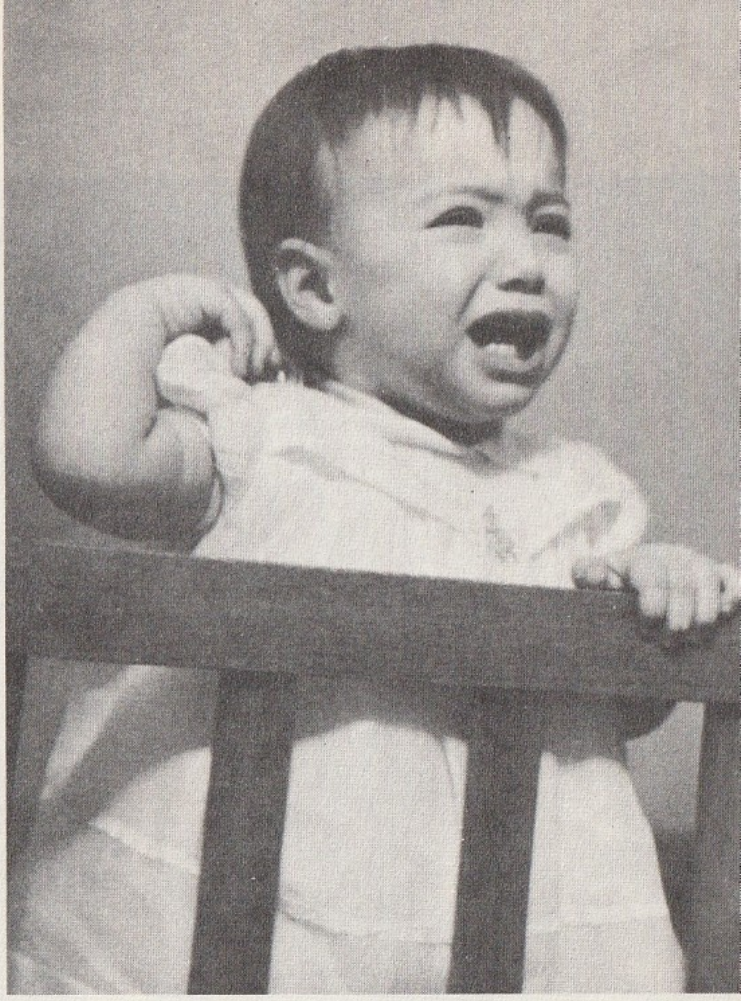
A number of nerve channels between the cochlea and the brain are so-called descending nerves, whose cells are oriented in such a way that they carry impulses from the brain *back* to the cochlea and its nerve system. These apparently supply the controlling impulses that block off the unwanted cross-connections. How these cross-connections are established is still a matter of speculation, but there is reason to believe that this "switching system", by altering the total length of the nerve routes

A Simple Experiment . . .

Here is one way to prove you can hear better with two ears than with one:

1. Sit in a chair in the middle of a room, and blindfold yourself.
2. Have a friend move very quietly to any part of the room and clap his hands sharply.
3. Point to where you think the friend is standing.
4. Repeat this several times, as your friend moves quietly from location to location. The friend can keep score on your accuracy.
5. Now place a hand tightly over one ear and repeat the experiment.
6. Finally, cover the other ear and repeat again.

If your hearing is normal, you should find that your score was higher when you listened with both ears uncovered.



Our hearing no more measures the characteristics of a sound than does our sense of touch measure pressure, or our sight measure light wavelength and intensity. It merely registers the characteristics and causes physical reactions to them.

traversed by the nerve impulses, changes the delay time between the signals from the two ears.

The extent of delay between the time of receiving the sound of a voice first at one ear and then at the other depends on the relative distances from the voice to each ear. At a crowded party, voices from different parts of the room involve very different "delay times". To single out a *particular* voice, it seems that we automatically "tune in" to the appropriate interval of delay and re-route the impulses from the ear nearest the sound source via a series of "nerve detours". In this way, the impulses from the second channel are able to reach the brain simultaneously only if they come from the source on which we have "tuned in". Other voices will continue to exhibit time delays—enough to enable the brain to recognize and reject them so long as we wish to concentrate our attention on a particular voice.

Learning to Hear

IT SHOULD NOW BE CLEAR that much of the process of hearing involves mental "interpretations" of the patterns of nerve impulses received

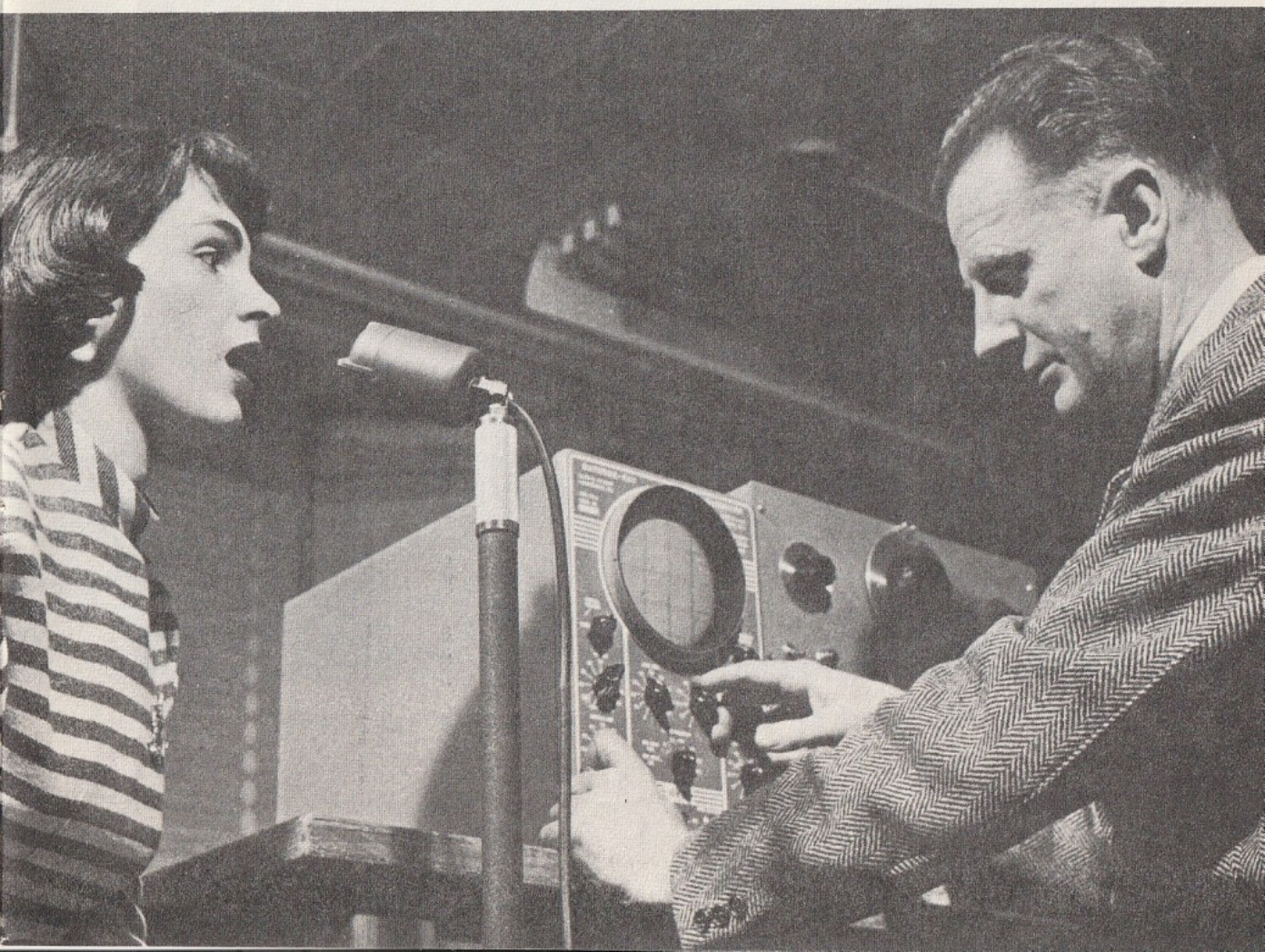
A therapist tape records the voice of a young girl suffering from speech and hearing defects. When the lesson is played back she will be helped to discover what articulation pattern will produce the sounds that practice will make easier.

by the brain. Some reactions, like the tightening of the "volume control" muscles, are reflex actions, which are beyond our conscious control and function automatically, like heartbeats. But most of our other reactions to sounds are *learned* after we come into this noisy world.

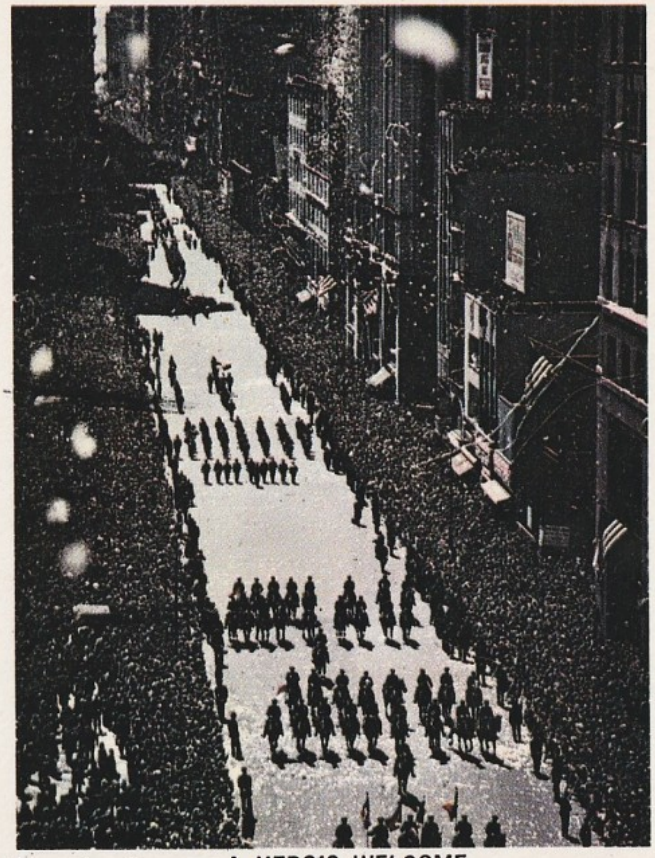
Although the infant at birth can detect sound waves, his hearing is completely unselective. He hears everything, but none of it has any meaning. It is all just so much disturbance. Differences in the pitch or loudness of sounds, in the absence of experience, are like messages in an unknown tongue.

After a few weeks, though, the infant starts to associate certain sounds with other things around him. As time goes on, he develops more complicated associations. He starts to integrate his hearing with all his other sensory perceptions, and some patterns start to emerge: "This" frequently

The sounds of speech can be displayed visually on the tube of an oscilloscope. In this way a person with a speech defect can match his signal trace with that of the instructor. This system is best for single syllables.



The din of demolition is high on the list of objectionable city noises.



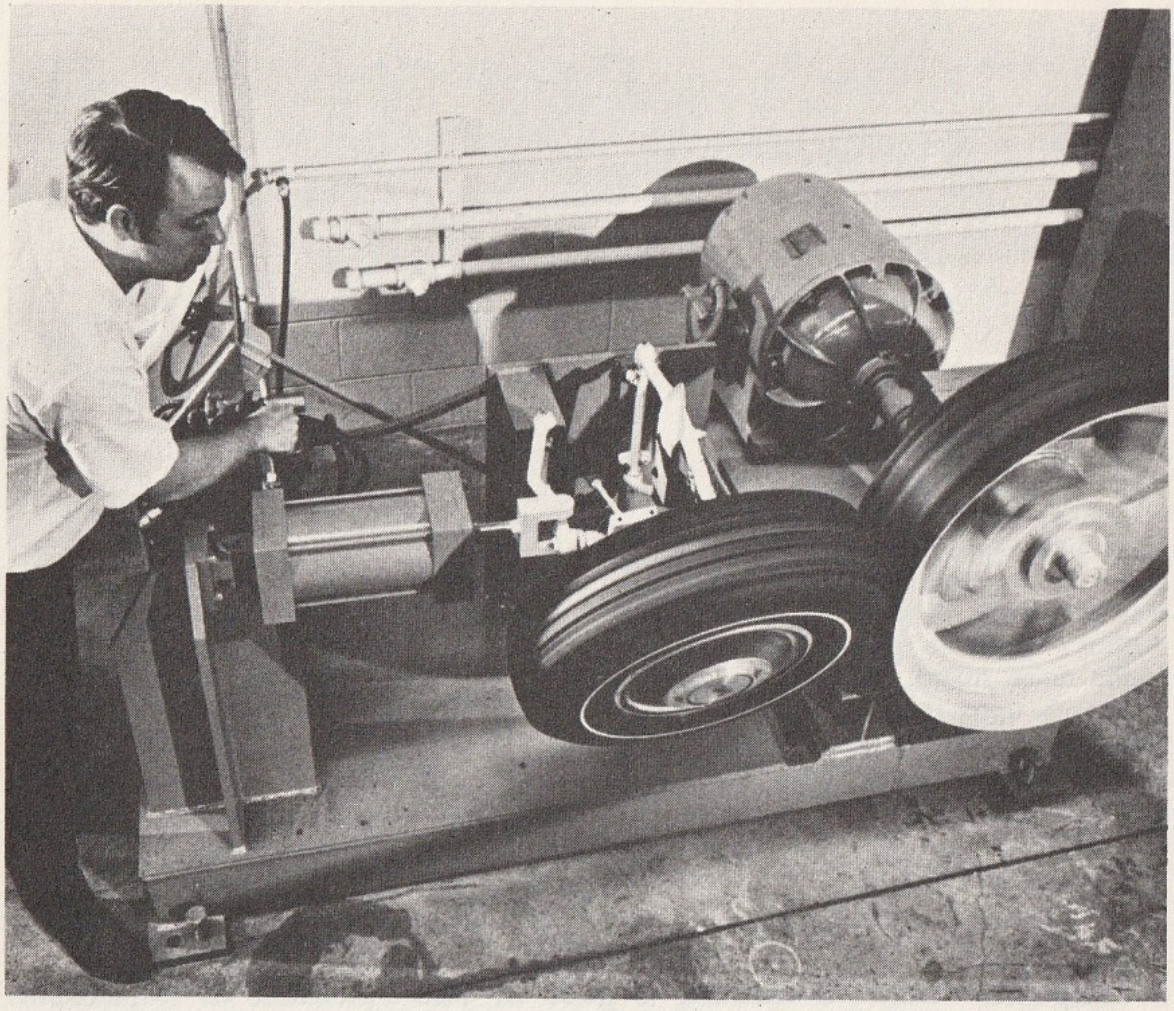
9. A HERO'S WELCOME

The "canyons" of New York City have no peer when it comes to a ticker-tape parade to welcome the conquering hero. This was the scene at General MacArthur's postwar parade. With traffic noise stilled, the sound of thousands upon thousands of human voices raised in acclaim has a special quality of its own.

accompanies "that". Something is good or bad—pleasant or unpleasant. His brain detects a time delay between the nerve impulses from his ears, and his eyes see where the sound is coming from, and the relationship is remembered. Later, when his brain hears the same time delay, it will "locate" the sound correctly *without* the aid of vision.

By the time he reaches age two, a child is rapidly learning to associate the sounds he himself makes with people, things and actions, and has learned to make speech sounds. Hearing plays a tremendously important role in the learning of speech, because without it we are not only unable to hear a word spoken to us, we are unable to hear how closely our own utterance sounds like it. Eventually, intelligible speech becomes so much of a habit that we no longer need to listen carefully to each sound we make. But this "feedback" system continues to control our speech without specific attention through our entire lives, and enables us to modulate our voices to suit the noise level of our surroundings.

We do not, however, hear ourselves as others hear us, because many of our vocal sounds reach our own cochlea by *bone conduction,* directly



Most people react emotionally to the dissonance of squealing rubber tires. This auto technician gets a steady diet of squeals while testing for cornering performance.

from our vocal chords through the skull bones. What we hear when speaking is a mixture of these bone-borne vibrations and the air-borne ones coming from our mouth back to our ears. This is one reason why a recording of your voice never sounds as natural to you as it does to your friends. Their ears, and the recording microphone, pick up only the air-borne speech sounds.

Our own recorded voices, and the voices of our friends, may sound different and completely individualistic to us; yet we have no trouble recognizing what is being said. The differences in fundamental pitch, harmonic structure, loudness and so on, do not interfere with our recogni-

tion of *speech patterns.* In listening to any sound, we don't try to analyze its frequency content and other physical characteristics. Instead, we hear complete patterns of vibrations that make sense to us because we have grown familiar with them.

A Frenchman uses similar speech sounds, but he arranges them in different patterns. Unless we have learned that language, the patterns elicit no associations at all and are meaningless to us. Yet we can listen to a shortwave broadcast in English, through a noisy static that obscures more than half of the sound vibrations, and have little trouble understanding what is being said. Our knowledge of the language helps to fill in the "missing bits" of sound patterns.

Our appreciation of music is largely a matter of learning, too. Simple rhythms and basic harmonies—the octave, for instance—are something that a young child can enjoy, even if he doesn't understand them. But the development of an "ear" for music takes appreciable training. Even the passive listener, who plays no instrument, develops more sophisticated tastes as he listens. Combinations of notes that may sound strange, or even unpleasant, at first, become acceptable with familiarity. And he may then move on to music with even more dissonances in it, and may learn to find them pleasant, too. But having developed his tastes on Western music, he might still be repelled by harmonies that Orientals find perfectly normal!

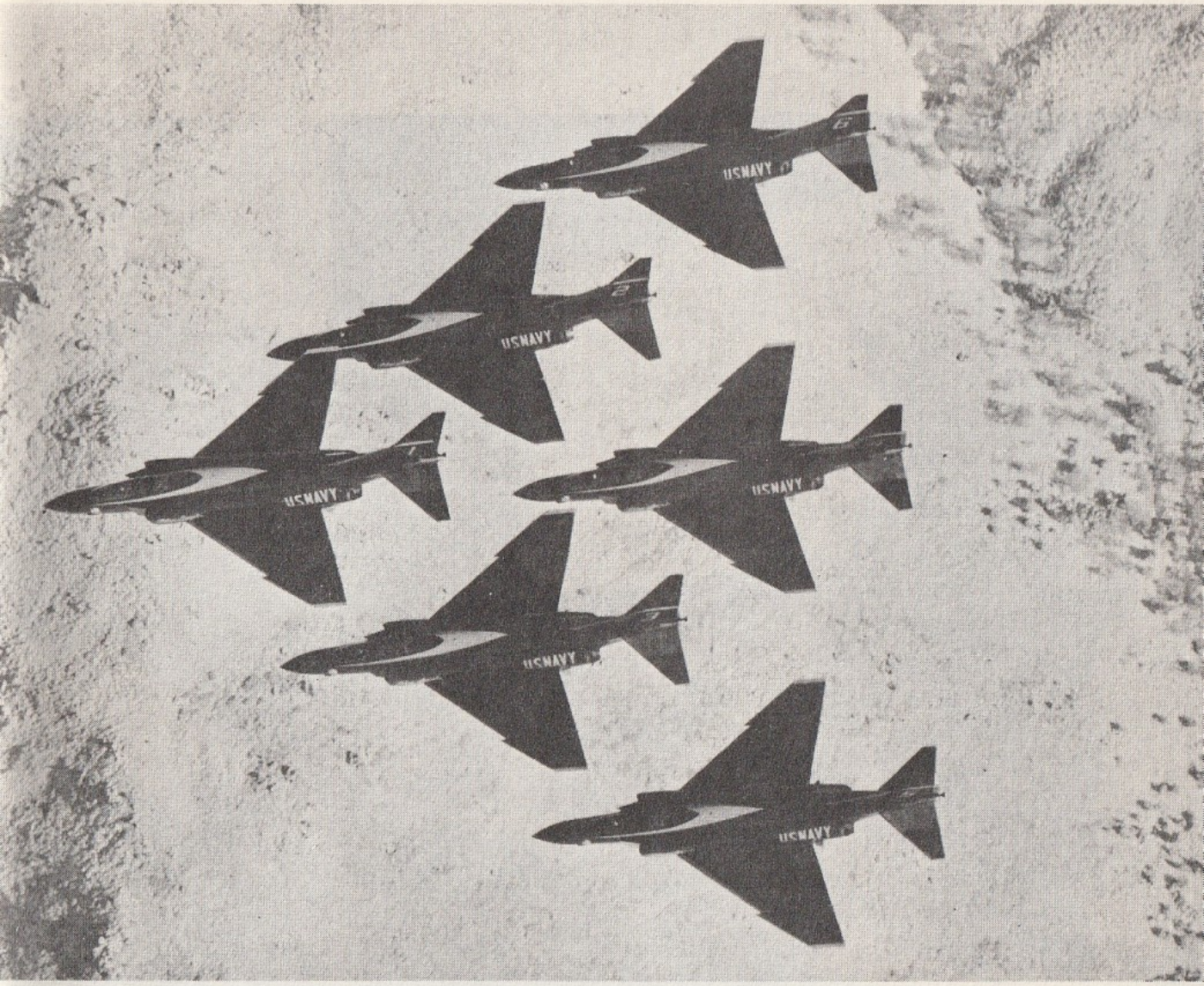
10. SYMPHONY ORCHESTRA

Members of the New York Philharmonic Symphony Orchestra during a rehearsal period. A symphony orchestra playing at full volume can reach a sound intensity level of almost 100 decibels.

Some musicians have what is called "perfect pitch", which is the ability to sing or play accurately from memory any desired musical pitch. It is not known why some people have this ability and not others.

Defects of Hearing

WHILE THE INTERPRETIVE ASPECTS of hearing can be developed through practice, the sound-detection aspect of hearing does not appear to be affected one way or the other by training. There is no known way of "limbering up" our ears the way we might build up our muscles through exercise. Our ears do not atrophy with disuse, and they do not

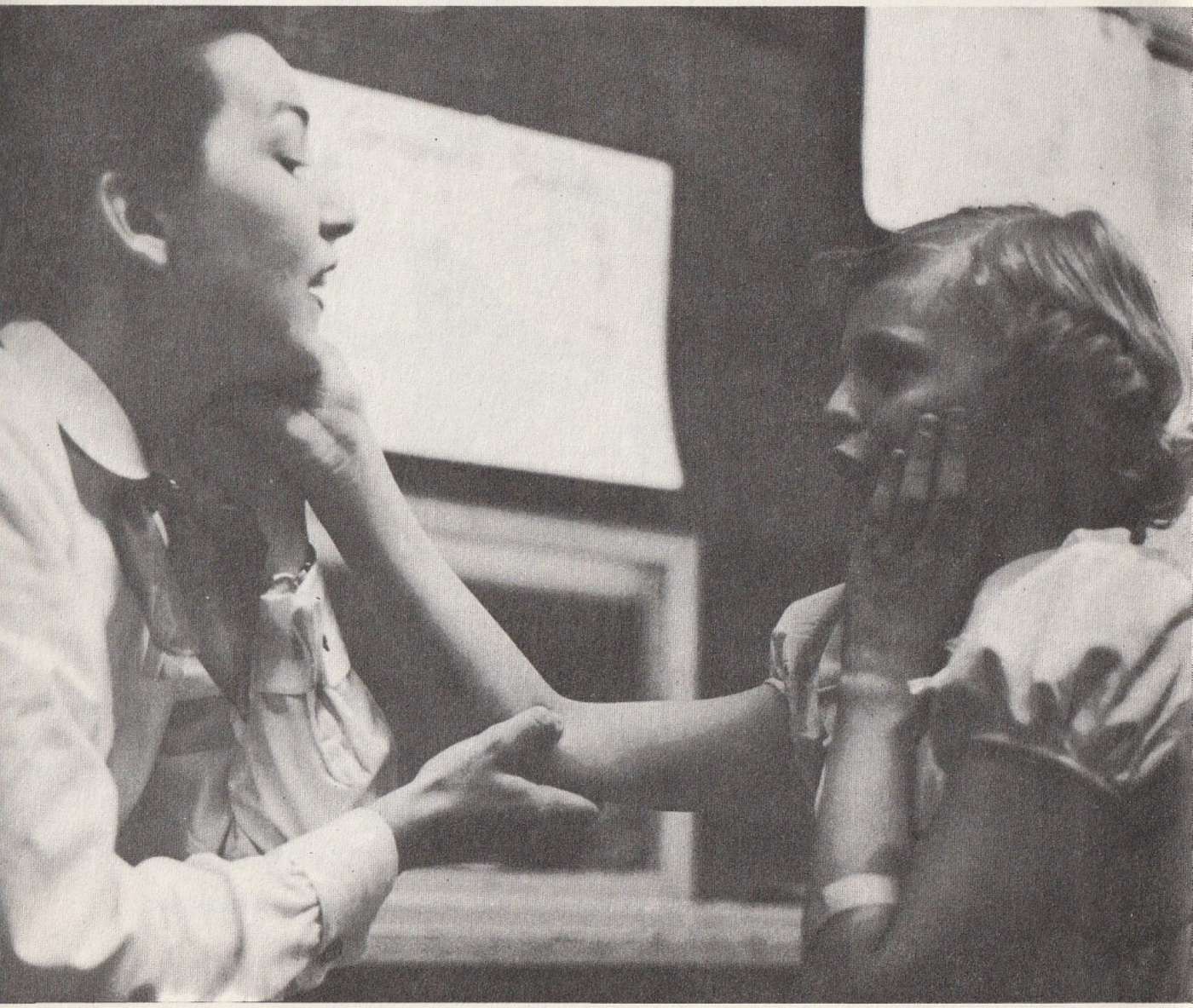


Navy jets in formation are pleasing to the eye, but can create noise discomfort.

wear out with normal use. But they *can* be damaged through *mis*use.

Normally, our ears are protected from loud sounds by the immobilizing action of the "volume control" muscles. But the eardrums are relatively fragile, and the cochlea nerve endings are exceedingly so. An extremely powerful sound may rupture the eardrum, causing a permanent impairment of hearing, but a less powerful sound can do permanent damage, too.

The reflex action of the volume control muscles is very rapid but not instantaneous. A very sudden, violent pressure wave, such as that from a nearby gun report, will get through to the inner ear before the muscles have had time to tighten, and will damage the cochlea's nerve endings. For some reason, most such damage occurs at frequencies around 7,000



Learning to speak by feeling the movement of muscles as well as vibrations to the surface of the skin. Throat microphones pick up these vibrations.

cycles per second, and the damage—a drastic loss of acuity at that frequency—is often permanent.

A continuous, loud sound will give the muscles time to pull tight, but it will nonetheless cause gradual impairment of hearing over a period of time. This kind of loss generally affects the entire hearing range, but the highest frequencies are most severely affected.

Normal aging causes loss of high-frequency acuity, too. As children, our upper limit of hearing sometimes extends to 20,000 cycles or slightly beyond, but as we pass age twenty, this upper limit moves very gradually downward. By the time we reach thirty-five years, our upper limit may still be around 15,000 cycles, but after that, the upper range restriction starts to advance rather rapidly. Some recent tests showed that most people over forty lose about 160 cycles per second of upper-frequency range every year.

11. HERE COMES THE BAND

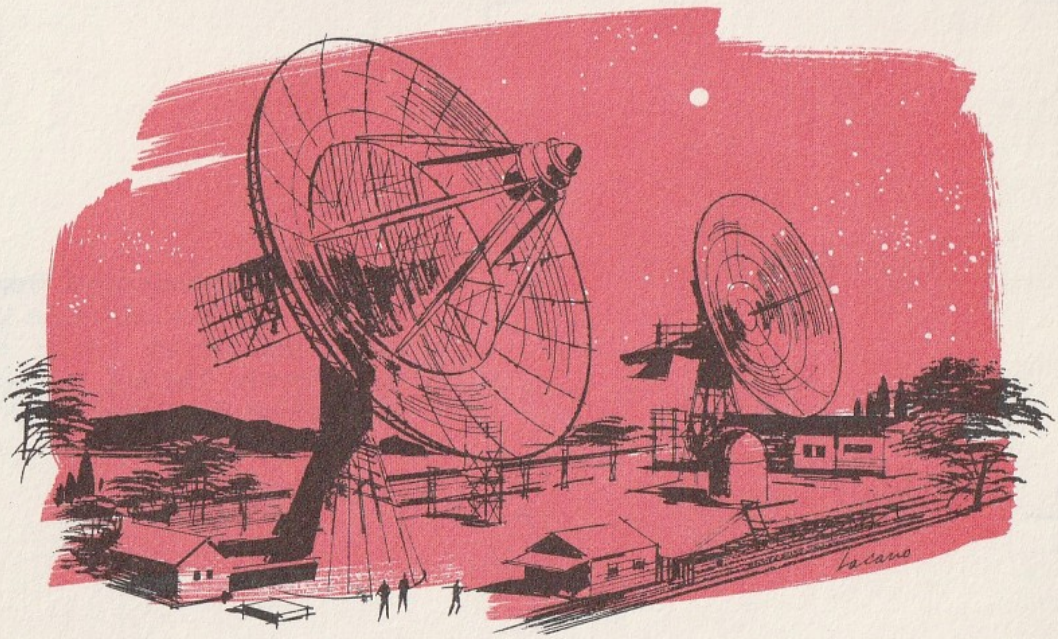
Watch a marching band from a distance and you will soon have proof that sound travels relatively slowly. The big, bass drum lags behind the visible "beat" of marching feet.

We do not usually notice this loss of treble range until it has advanced quite far. It takes place so gradually that we become accustomed to the restriction until it starts to interfere with our comprehension of speech. The high-frequency losses erase the sibilants and "T" sounds first, and the other high-frequency components of speech are the next to go. Along with the treble loss, there may also be some loss of acuity throughout our whole range, but a hearing aid will usually make up for any loss that is not total.

Severe deafness cannot be helped much by making the sounds louder, so whether or not this condition is remediable depends on the cause of the deafness. If the deafness is *conductive*—that is, affecting only the transfer of air vibrations to the cochlea—there are several possible remedies. Cor-

rective surgery may help, or a bone conduction hearing aid may get sounds through to the cochlea well enough to restore useful hearing. But if the impairment is due to deterioration of the hearing nerves or their endings, there is nothing that can be done to restore the hearing.

A hearing aid can never equal a good pair of ears, so rather than rely on remedial measures after the fact, it is wiser to take good care of our ears. Sharp ears don't have to warn us of cave lions any more . . . but they are priceless for communication with our fellow man.



Noise Pollution—and Your Health

WHEN SOUND HAS an undesirable effect, and is unwanted, we call it noise. Today the world is growing constantly noisier. Noise can be more than a mere nuisance and is taking its place alongside air pollution and water pollution as a major and growing concern—for too much noise can be as dangerous to our well-being as dirty air or filthy water.

In civilized countries all over the world, noise has become a serious economic and social problem. More and more jet planes scream overhead, unmuffled trucks and motorcycles roar down highways, outboard

motors reverberate across placid lake waters, sports cars whine through once-quiet streets. Complaints are mounting about TV sets and hi-fi record players and stereo systems blaring into the night.

The cacophony is increased inside the home by airconditioners, vacuum cleaners, food blenders and garbage disposal units. Outside the home the pitch is raised by police, fire and ambulance sirens, car horns, power mowers, cement mixers, air hammers and roaring buses.

This is what is meant by "noise pollution", with people being exposed to the highest and most dangerous noise levels in history.

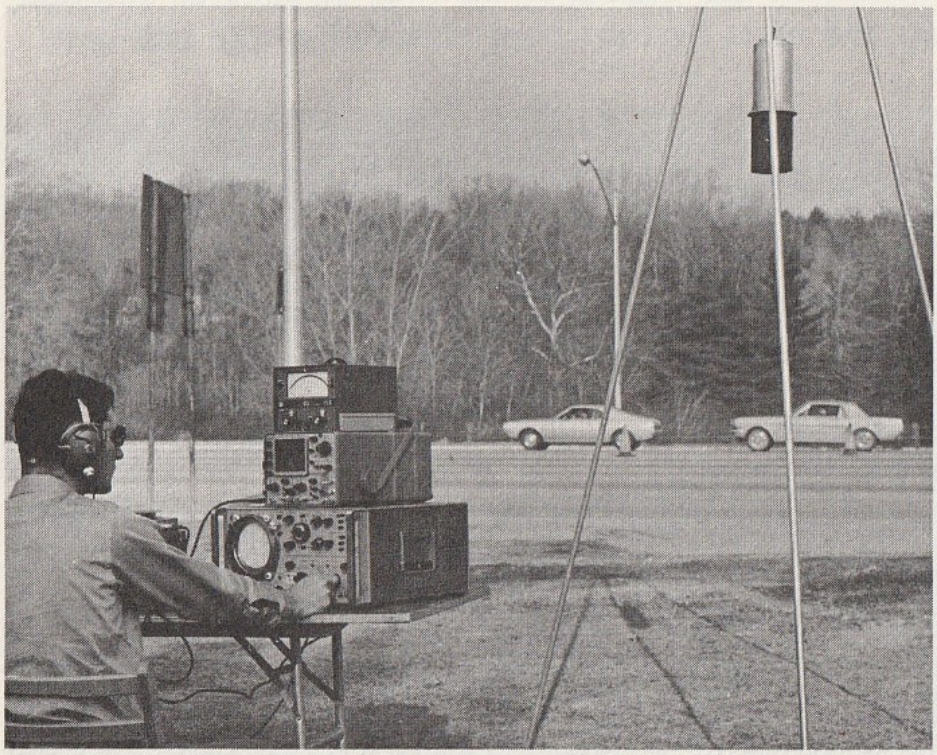
When strong enough, noise can kill fish, break a wine glass, burst a plate glass window, undermine the structural foundations of a large building—and damage parts of the human body. The most obvious damage to the body is deafness. Just as a pistol blast, at close range, can rupture an eardrum, similarly sudden and unexpected noises from other sources can produce potentially harmful changes in bodily activity, as the body's defensive mechanism reacts to an unknown stimulus. Perspiration increases, blood pressures rise, muscles contract sharply and digestion ceases. A high-intensity noise—above 135 decibels—can cause a breakdown in the ear's sensitive basilar membrane. Loud noise also causes unpleasant sensations, such as vibrations of the eyeballs and head, loss of equilibrium and heating of the skin. A noise of 160 decibels can kill rats and mice, by conversion of sound energy into heat.

Citizens' groups in some cities would like to ban helicopter traffic because of the noise.

Meaning of Decibels

AS SHOWN ON THE CHART on Page 27, sound is measured on a scale of about 120 decibels, with one representing the faintest audible sound and 120 indicating the threshold of feeling pain. The word decibel comes from *deci,* for a value of ten, and *bel* after Alexander Graham Bell who is responsible for the telephone and its ring. Decibel levels are the number of sound waves coming from a vibrating body such as the larynx, a loudspeaker, or an air hammer. On that scale:

- The average residence with a busy kitchen, television and vacuum cleaner can measure up to fifty decibels.
- A truck roaring by twenty feet away produces eighty decibels. Experts agree that prolonged exposure to sound levels of eighty-five decibels or more is almost certain to lead to some degree of hearing loss.
- Train whistles at 500 feet produce up to ninety decibels and a subway train at fifty feet produces up to 100 decibels.
- Construction noise with compressors and hammers breaks the 110-decibel level, and so do motorcycles, electric lawn mowers and tractors.
- A jet plane at 500 feet registers up to 115 decibels, and rock music at its peak about 120 decibels.



Noise levels of passing vehicles are monitored by highly sensitized electronic devices during a noise-pollution measurement project in Connecticut.

Rock 'n' Roll Can Hurt

THE AVERAGE TEENAGER, listening to a rock band that is hooked up to amplifiers, is exposed to as much noise as an artilleryman or a foundry worker. The great difficulty in convincing youngsters that this is harmful lies in the fact that they want to feel "embalmed" or somewhat numb. Noise often peaks at 120 decibels in front of the band, and at 106 decibels at the middle of the dance floor. The intensity of sound in front of a rock band can cause a temporary hearing loss, and with repeated exposure actually damage the delicate nerve endings of the inner ear.

Workers in noisy surroundings often complain of ailments such as nausea, fatigue, headache, loss of muscular co-ordination. And, of course, if noise does nothing more than interfere with sleep, it is a menace to good health. Physicians say that continued fitful sleep may lead to ulcers, high blood pressure and even heart attacks.

Noise can affect mental health by creating stress, tension and irritability. It was found in Great Britain that people living around London's Heathrow Airport had a higher rate of admission to mental hospitals than people living in quieter areas close by.

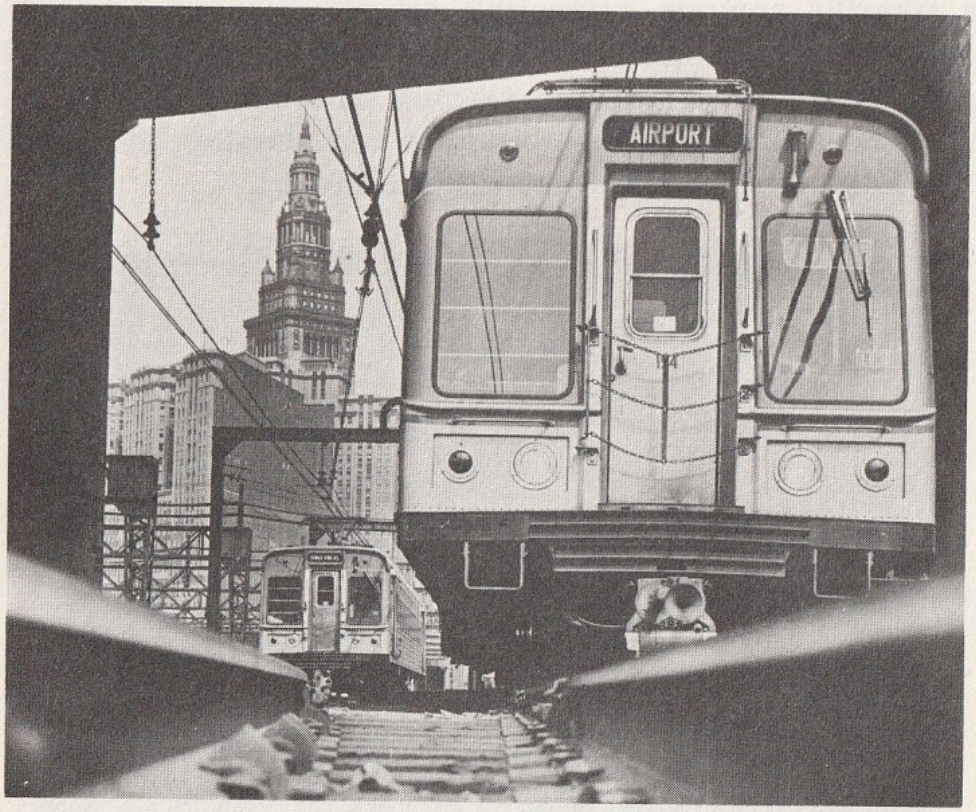
Noise adversely affects human efficiency. The U.S. Air Force has found that a normally accurate, responsible aircraft mechanic may unconsciously rush through his job, in a slipshod way, if he happens to be working near a whining jet exhaust. Overall, noise costs U.S. industry almost a billion dollars a year in workmen's compensation for noise-related injuries, lost man-hours and decreased efficiency.

One of the few places where the roar of jet engines is taken in stride is at an air show.

What Can Be Done?

PEOPLE ARE GETTING CONCERNED about noise pollution as never before. But what, really, can be done? For one thing, more and more communities are striving to develop noise-abatement programs. Some are trying to divert aircraft noise by routing the approach and departure of planes away from densely populated areas. Many modern plants are employing acoustical engineers to tell them how to cut down on noisy operations. People are demanding better insulation in apartments and homes and offices, and architects are beginning to comply. A big drive is under way to develop quieter autos, trucks and buses. Some cities are seeking ways to prevent some of the noise made by trash and garbage collectors. Tighter rules are being drawn up on motor sounds, and efforts are under way to lower the din of construction and demolition through the use of quieter tools.

Many citizens are encouraged by the fact that the Federal government is showing more interest in doing something about reducing noise levels. They hope for further progress, along the lines of air-pollution and water-pollution standards that have already been set up on a nationwide scale. All in all, however, noise pollution is a long-neglected problem that requires much more attention.



Rapid-transit cars, above ground and below, are a major problem for many cities seeking greater quiet.

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